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Electrification Roadmap: Town of Acton and Acton-Boxborough Regional School District

Acton, Massachusetts

July 20, 2022
2021-04804-00

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Executive Summary

This Electrification Roadmap is a strategic planning tool created for the Town of Acton and the Acton-Boxborough Regional School District (ABRSD) for the electrification of HVAC systems serving seven key buildings, three in the Town of Acton and four in the ABRSD. The Town of Acton buildings include the Acton Memorial Library, Acton Town Hall, and the Public Safety Facility. The ABRSD buildings include the Acton-Boxborough Regional High School, Administration Building, Parker Damon Building, and the RJ Grey Junior High School.

The consultant team, Salas O'Brien, consulted with town and school district facilities and energy management staff, reviewed existing building documentation, utility bills, and conducted site surveys to understand the building operations and maintenance requirements, deferred maintenance, capacity, inventory, and remaining service life of existing HVAC equipment.

The Electrification Roadmap recommendations include transitioning from fossil fuel-based heating systems to high efficiency Air Source Heat Pumps (ASHPs), while utilizing electric boilers and traditional electric chillers for peak heating and cooling requirements, where necessary. By utilizing all-electric equipment for building HVAC systems, fossil fuel-based greenhouse gas (GHG) emissions associated with the heating and cooling systems are eliminated. In addition, as the Massachusetts electricity grid shifts to 100% renewably sourced energy by 2050, the GHG emissions associated with purchased electricity will eventually be eliminated, resulting in the seven buildings included in this Electrification Roadmap producing zero GHG emissions via their heating and cooling systems. The total avoided GHG emissions from the Electrification Roadmap are summarized in Table 1 below.

Table 1: Avoided Greenhouse Gas Emissions via Building Electrification

	Avoided GHG Emissions Through 2051 (MTCO2e)
Town of Acton	6,050
ABRSD	13,108
Town of Acton + ABRSD	19,157

Town of Acton: The Electrification Roadmap recommendations for the Town of Acton buildings will require a $6.7M capital investment over eight years, 2022 - 2030, compared to the $0.9M capital investment required for the business as usual (BAU) case. Over the 30-year Life Cycle Cost Analysis (LCCA), the proposed electrified systems option costs $5.5M over the BAU case.

Figure 1 depicts the implementation timeline to electrify the town buildings by the Town of Acton's 2030 Climate Emergency Declaration goal.

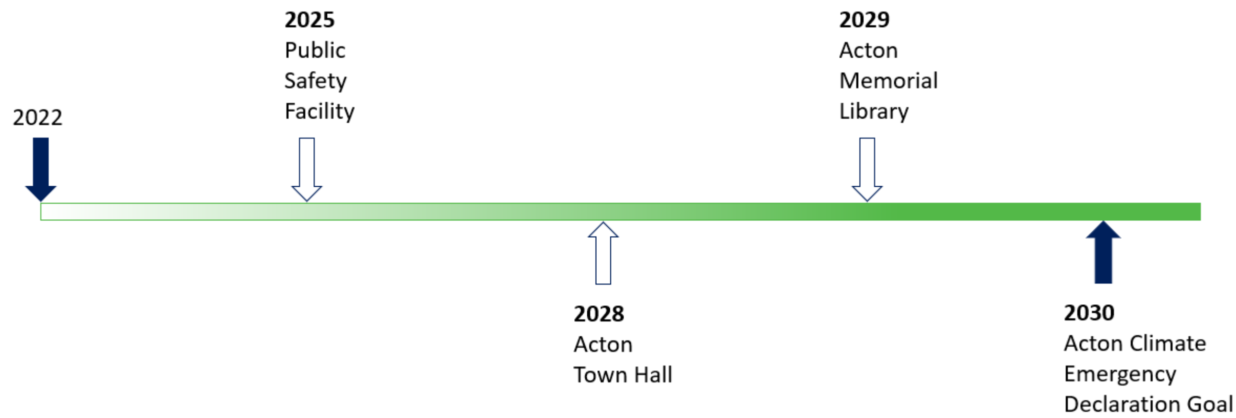

Figure 1: Town of Acton Electrification Implementation Plan

ABRSD: The Electrification Roadmap recommendations for the ABRSD buildings will require a $22M capital investment over 28 years, 2022 - 2050, compared to the $7.6M capital investment required for the BAU case. Over the 30-year LCCA, the proposed electrified systems option costs $14.9M over the BAU case.

Figure 2 depicts the implementation timeline to electrify the ABRSD buildings by 2050.

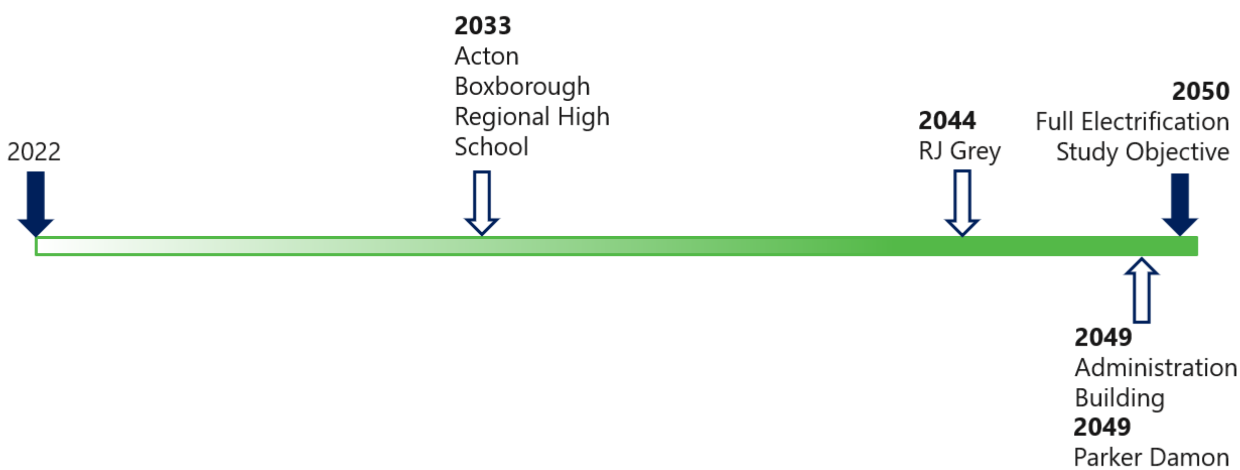

Figure 2: ABRSD Electrification Implementation Plan

The total capital investments for both the Town of Acton and ABRSD for both the BAU and the electrification option are summarized in Table 2 below, in 2022 dollars. Additional 30-year LCCA results for the Town of Acton and the ABRSD are included in Table 63 through Table 66.

Table 2: Electrification Recommendation Capital Cost Comparison vs. BAU (2022)

	BAU Capital Costs	Electrification Capital Costs
Town of Acton	$867,242	$6,709,989
ABRSD	$7,629,167	$22,050,759

Electrification of the seven buildings outlined in this report will contribute to the Town of Acton's Climate Emergency Declaration to eliminate carbon emissions by 2030 and is aligned with the Acton-Boxborough Regional School District's track record for actively pursuing energy conservation and efficiency measures. This Electrification Roadmap is also aligned with the ambitious decarbonization targets set by the Commonwealth of Massachusetts in the 2021 Next Generation Roadmap climate legislation.

Project Team

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• J.D. Head, Director of School Operations • Kate Crosby, Energy Manager • Anthony Wassel, Custodial and Maintenance Supervisor
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List of Abbreviations

A	Ampere (Amp)
ABRHS	Acton-Boxborough Regional High School
ABRSD	Acton-Boxborough Regional School District
AC	Air Conditioning
AEC	Advanced Energy Credits
AHU	Air Handling Unit
APS	Alternative Energy Performance Standard
ASHP	Air Source Heat Pump
BAU	Business as Usual
CHW	Chilled Water
COP	Coefficient of Performance
DOER	Department of Energy Resources
DHW	Domestic Hot Water
DX	Direct Expansion (refrigerant based)
ECM	Energy Conservation Measure
EIA	Energy Information Administration
EPA	Environmental Protection Agency
ERV	Energy Recovery Ventilator
ETS	Emissions Trading System
FCU	Fan Coil Unit
GSHP	Ground Source Heat Pump
GHG	Greenhouse Gas
HP	Horsepower
HR	Heat Recovery
HTHW	High Temperature Hot Water
HVAC	Heating Ventilation and Air Conditioning
kV	Kilovolt
kVA	Kilovolt-Ampere
kW	Kilowatt
LCCA	Life Cycle Cost Analysis
LTHW	Low Temperature Hot Water
MBH	Thousand British Thermal Units per Hour
MTCO2	Metric Ton of Carbon Dioxide
MTCO2e	Metric Ton of Carbon Dioxide Equivalent
MVP	Municipality Vulnerability Preparedness
NG	Natural Gas
PSF	Public Safety Facility
PV	Photovoltaic
RFO	Renewable Fuel Oil
RTU	Roof Top Unit
SF	Square Feet
V	Volt
VAV	Variable Air Volume
VRF	Variable Refrigerant Flow

Introduction

The Town of Acton, in collaboration with the Acton-Boxborough Regional School District (ABRSD), received grant funding from the Massachusetts Municipality Vulnerability Preparedness (MVP) program for the development of a comprehensive Electrification Roadmap, identifying strategies for electrification of seven key public buildings. Salas O'Brien was engaged to develop the Electrification Roadmap to identify a pathway for full electrification of the seven buildings by converting fossil fuel-based HVAC systems to all-electric HVAC systems. The Electrification Roadmap also includes recommendations for electrical infrastructure upgrades required to support electrification, photovoltaic (PV) feasibility, and back-up generation options.

Of the seven public buildings included in the Electrification Roadmap, three are owned by the Town of Acton and four are owned by ABRSD. A summary of the seven buildings is included below in Table 3.

Table 3: Building Summary

Building	Area (SF)	Year Built	Recent Renovations
Town of Acton			
Acton Memorial Library	48,259	1889	2018
Acton Town Hall	24,144	1864	2015
Public Safety Facility	26,033	2005	-
ABRSD			
Acton-Boxborough Regional High School (ABRHS)	386,000	1964	2005
Administration Building	36,000	1959	-
RJ Grey Junior High	143,000	1955	2002
Parker Damon	142,000	2001	-

The Town of Acton adopted a Climate Emergency Declaration at Town Meeting in September 2020 calling for net zero carbon emissions as quickly as possible, with a target date of 2030. In support of meeting the Town's carbon emission reduction targets, the new North Acton fire station includes geothermal HVAC systems and onsite PV, and the Town is currently pursuing an onsite PV installation at the Public Safety Facility, capable of providing 80% of the building's required annual electricity. The Town received a Leading by Example award by the Department of Energy Resources (DOER) in December 2021 for spearheading initiatives aimed at reducing environmental impacts and associated energy costs of government operations.

ABRSD has aggressively pursued energy conservation and efficiency, achieving a 30% reduction in electricity and natural gas use over the 2009 benchmark year. ABRSD will be opening a new all-electric geothermal Net Zero Energy school building in Summer 2022, which will be powered by a large rooftop solar array and a parking canopy solar array, as well as a battery storage array. Solar arrays and a battery storage array also help to power the District's main campus.

With increasing support for climate action among residents, it is hoped that the Electrification Roadmap will not only identify pathways for electrifying municipal and school buildings, but will also encourage Acton residents to investigate residential electrification opportunities.

Existing Building Systems

Town of Acton Buildings

Acton Town Hall

Acton Town Hall is a three-story, 24,144 SF municipal office building built in 1864 and most recently renovated in 2015. The building is heated, cooled, and ventilated by two-pipe Fan Coil Units (FCUs) throughout the building. During the heating season, High Temperature Hot Water (HTHW) is provided to the FCUs by a 491 MBH input natural gas boiler. During the cooling season, Chilled Water (CHW) is provided to the FCUs by a 40 Ton air-cooled chiller. In addition to the FCUs, a Variable Refrigerant Flow (VRF) system consisting of three indoor units and one outdoor unit provides additional heating and cooling to the building's north wing office, small meeting room/kitchenette, and medium conference room.

The existing electrical service is a 480/277 V, 3-phase, 4-wire system with a step-down transformer to 208/120 V. The building is fed via a 13.8 kV underground service to a pad-mounted transformer feeding a 600 A, 208/120 V, 3-phase, 4-wire main distribution board "MDP." The building is backed up via a 50 kW, 208/120 V, 3-phase, 4-wire diesel generator via a 200 A transfer switch.

Acton Memorial Library

Acton Memorial Library is a three-story, 48,259 SF library built in 1889 and most recently renovated in 2018. The building is heated by a 1,876 MBH input natural gas boiler that provides HTHW to finned-tube radiators, hydronic unit heaters, and hydronic reheat coils in VAV boxes throughout the building. Additional heating, as well as cooling and ventilation is provided by four Rooftop Units (RTUs) with gas-fired heat and DX cooling with a total heating capacity of 1,332 MBH and a total cooling capacity of 102 Tons.

The existing electrical service is a 1600 A, 208/120 V, 3-phase, 4-wire system. The building is fed via a 13.8 kV underground service to a pad-mounted transformer feeding a 1600 A, 208/120 V, 3-phase, 4-wire main switch board "SWBD." The building utilizes a 60 kW, 208/120 V, 3-phase, 4-wire natural gas generator via a 200 A transfer switch for emergency loads. In addition, the building utilizes a 30 kVA UPS for backup of miscellaneous electronic loads.

Public Safety Facility

Public Safety Facility (PSF) is a two-story, 26,033 SF police station and fire administration office built in 2005. The building is heated by a modular natural gas boiler with four sections, each with a 300 MBH input capacity, totaling 1,200 MBH input capacity. The boiler provides HTHW to hydronic heating coils in AHUs, unit heaters, and VAV boxes with hot water reheat coils. The building is cooled and ventilated by four AHUs with DX cooling coils and remote air-cooled condensers with a total cooling capacity of 65

Tons. Additional cooling is provided to the communications equipment room, data room, dispatch room and armory by four mini-split DX air conditioning units with a total cooling capacity of 10 Tons.

The existing electrical service is a 208/120 V, 3-phase, 4-wire system. The building is fed via a 13.8 kV underground service to a pad-mounted transformer feeding a 1200 A, 208/120 V, 3-phase, 4-wire switchboard “SB2”. The building is backed up via a 250 kW, 208/120 V, 3-phase, 4-wire diesel generator via a 1000 Amp transfer switch. The PSF includes a 100 kW, 208/120 V, 3-phase, 4-wire portable generator connection via a 400 A transfer switch for backup of panel “EP2” and a 20 kVA UPS System for the dispatch room equipment.

Acton-Boxborough Regional School District Buildings

Acton-Boxborough Regional High School

The Acton-Boxborough Regional High School is a 386,000 SF academic building built in 1964 with a 1971 addition and major renovation and addition in 2005. The building is heated by a 24,500 MBH input natural gas-fired boiler system consisting of three 8,165 MBH fire-tube boilers installed in 2005 that provide HTHW to a hydronic distribution system. The hydronic distribution system serves heating coils in 21 roof mounted AHUs, fin tube radiation, unit heaters, unit ventilators, hot water reheat coils, VAV boxes and radiant panels. The building is also heated by 14 gas-fired RTUs. The building is cooled by DX systems located in RTUs with a total cooling capacity of 830 Tons as well as by a 45 Ton air-cooled chiller serving unit ventilators. Ventilation is provided to the building with RTUs and unit ventilators. The pool is heated by an electric heater and natural gas boiler.

The existing electrical service is a 3000 A, 480/277 V, 3-phase, 4-wire system. The building is fed via a 13.8 kV underground service to a 2500 kVA pad-mounted transformer feeding a 3000 A, 480/277 V, 3-phase, 4-wire main switchboard “MSB-A.” “MSBA” sub feeds the 1971 addition 1600 A switchboard “MDO-C.” The 2005 addition is fed via a 13.8 kV underground service to a 1000 kVA pad-mounted transformer feeding a 1600 A, 480/277 V, 3-phase, 4-wire main switchboard “MSB-B.” The building utilizes a 250 kW, 480/277 V, 3-phase, 4-wire natural gas generator via a 200 A transfer switch for emergency loads.

RJ Grey Junior High School

RJ Grey Jr High School is a one-story, 143,280 SF academic building built in 1955, with a major renovation in 2002. The building is heated by a 7,200 MBH input natural gas-fired boiler system consisting of four 1,800 MBH condensing boilers installed in 2014 that provide HTHW to a hydronic distribution system. The hydronic distribution system serves heating coils in nine AHUs, fin tube radiation, unit ventilators and hot water reheat coils. The building is also heated with eight gas-fired RTUs with a total capacity of 2,900 MBH. The building is cooled by DX RTUs, split system air conditioners, and through the wall AC units. The RTUs have a combined cooling capacity of 122 Tons. The through-the-wall AC units and split systems have a combined cooling capacity of 26 Tons. Ventilation is provided via RTUs and unit ventilators.

Also included on the RJ Grey site is a 1,200 SF modular Facilities Building which is heated and cooled with air-source heat pumps and supplemental electric resistance baseboard heating.

The existing electrical service is a 2000 A, 480/277 V, 3-phase, 4-wire system. The building is fed via a 13.8 kV underground service to a pad-mounted transformer feeding a 2000 A, 480/277 V, 3-phase, 4-wire main switch board “MSB.” The building utilizes a 25 kW diesel generator for emergency loads.

Parker Damon Building

The Parker Damon Building is a three-story 142,151 SF academic building built in 2001. The building is heated by a 5,000 MBH natural gas-fired boiler system consisting of two 2,500 MBH condensing boilers installed in 2015 that provide HTHW to unit ventilators, ducted FCUs and fin tube radiation. The building is also heated with ten gas-fired RTUs with a total capacity of 2,020 MBH. The building is cooled by nine DX RTUs with a total cooling capacity of 131 Tons and a 224 Ton air cooled chiller serving unit ventilators and ducted FCUs. Ventilation is provided to the building with RTUs, ducted FCUs and unit ventilators.

The existing electrical service is a 2,500 A, 480/277 V, 3-phase, 4-wire system. The building is fed via a 13.8 kV underground service to a pad-mounted transformer feeding a 2,500 A, 480/277 V, 3-phase, 4-wire main switch board “MSB.” The building utilizes a 100 kW, 480/277 V, 3-phase, 4-wire diesel generator via a 200 A transfer switch for emergency loads.

Administration Building

The Administration Building is a two-story, 36,000 SF academic/administrative building built in 1959. The building is heated by a 2,224 MBH input natural gas boiler system consisting of two 1,112 MBH condensing boilers installed in 2014 and 2021 that provide HTHW to hydronic heating coils in AHUs and unit heaters. The building is partially cooled by DX systems in AHUs, split systems air conditioners and window AC units with an estimated total cooling capacity of 40 Tons. Ventilation is provided via operable windows and AHUs.

The existing electrical service is a 1,200 A, 208/120 V, 3-phase, 4-wire system. The building is fed via a 13.8 kV overhead service to a pad-mounted transformer feeding a 1,200 A, 208/120 V, 3-phase, 4-wire main switch board with a 1,200 A main breaker. The building currently has no emergency backup system.

Growth Forecast

Additional Cooling - Administration Building

Based on feedback from ABRSD staff, the Administration Building is planned to be fully cooled during its next major renovation. In this study, the Administration Building was modeled as fully air conditioned, with a typical office building cooling load of 400 SF/Ton and total cooling load of 90 Tons.

All other buildings included in this study were modeled with their current heating and cooling loads. No additional building renovations or building additions have been included in this analysis.

Business as Usual (BAU) Forecast

The BAU forecast forms the foundation for a comparison of the relative costs and benefits of the recommended electrification option included in this study. It includes a forecast of energy consumption and cost, operations and maintenance expenses, energy system capital expenditures, and GHG emissions. The BAU case outlines the historic and forecasted GHG emissions and energy consumption for all seven buildings through 2051. The BAU forecast is based on historical energy performance of each building and has been forecasted through 2051. For the Town of Acton buildings, the BAU forecast includes energy use from 2017 to 2021, while ABRSD's BAU forecast is based on energy use from 2016 to 2019. The 2020 to 2021 energy use for the ABRSD was not used in this analysis as normal school district operations were disrupted by the COVID pandemic, resulting in reduced atypical energy consumption.

Utility cost calculations for both Town of Acton and ABRSD buildings are based on several assumptions detailed in the Utility Costs section. The electricity and natural gas GHG emissions factors used to calculate GHG emissions are included in Table 4.

Table 4: Greenhouse Gas Emission Factors

Utility CO2e Emissions Factors – 2022	
Electricity (lb CO2e/KWH)	Natural Gas (lb CO2e/Therm)
0.658	11.70

Acton Town Hall

The annual heating and cooling load profile for the Acton Town Hall BAU case is included below in Figure 3. The thermal profile summarizes the existing heating and cooling loads for the Town Hall, with the cooling loads shown in blue and the heating loads shown in red. The two key components of this thermal profile are the average monthly thermal peaks and total energy consumed.

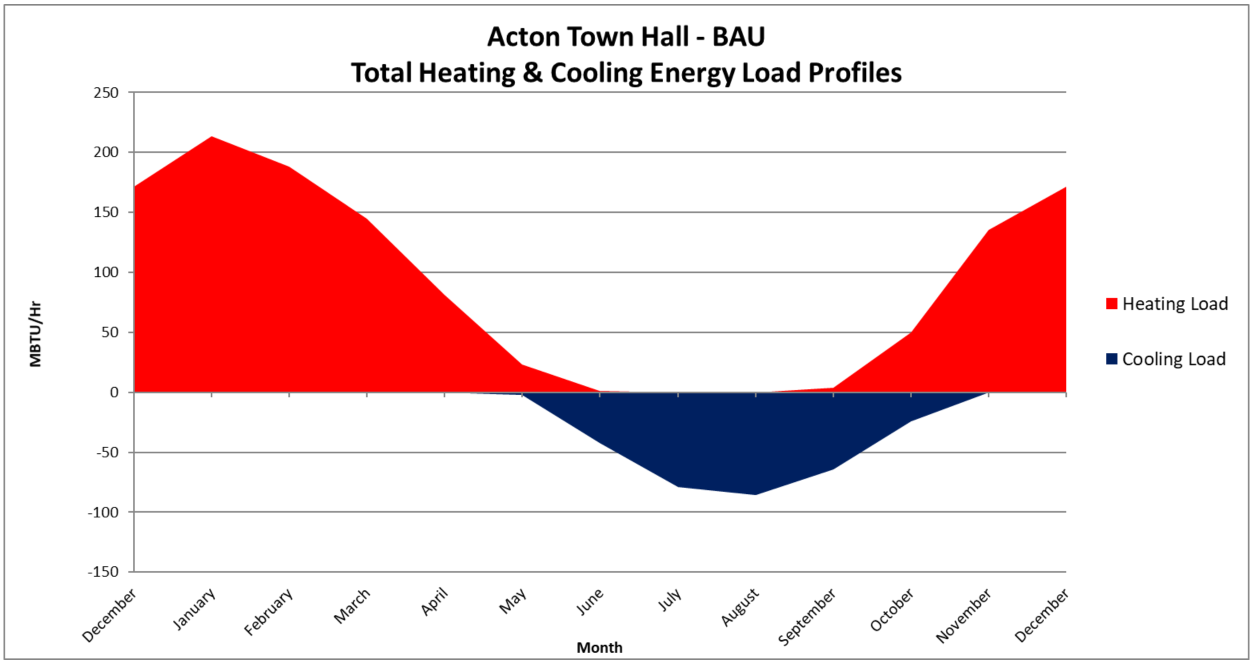


Figure 3: Acton Town Hall BAU Thermal Profile

The predicted energy use, carbon footprint and utility costs for the Acton Town Hall BAU case today (2022) are summarized below in Table 5, Table 6 and Table 7.

Table 5: Acton Town Hall BAU HVAC System Energy Consumption (2022)

	BAU System
Electric Heating/Cooling (KWH/yr)	26,922
Natural Gas Heating (Therm/yr)	11,536
TOTAL Heating/Cooling (MBTU/yr)	1,245,485

Table 6: Acton Town Hall BAU HVAC System Utility Costs (2022)

	BAU System
Electric Heating/Cooling Utility ($/yr)	$5,573
Natural Gas Heating Utility ($/yr)	$13,728
TOTAL Heating/Cooling Utility ($/yr)	$19,301

Table 7: Acton Town Hall BAU HVAC System GHG Emissions (2022)

	BAU System
Electric Heating/Cooling (MTCO2e/yr)	8
Natural Gas Heating (MTCO2e/yr)	61
TOTAL Heating/Cooling (MTCO2e/yr)	69

Acton Memorial Library

The annual heating and cooling load profile for the Acton Memorial Library BAU case is included below in Figure 4.

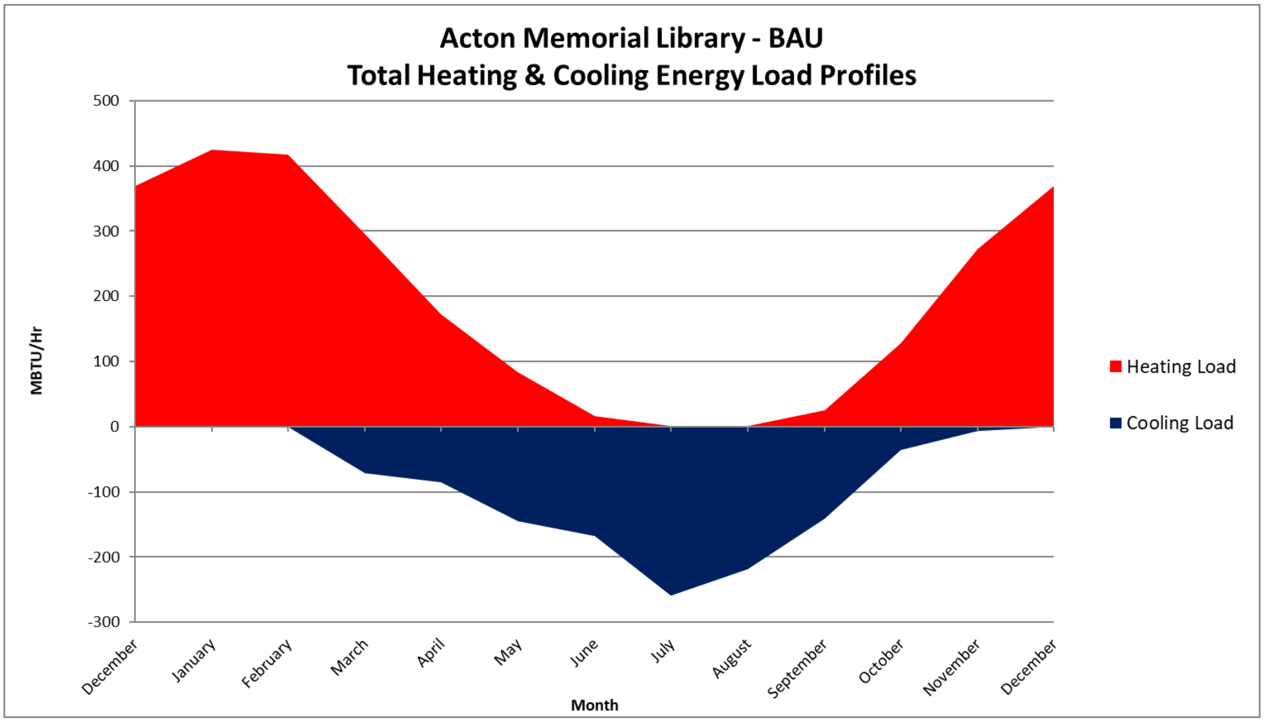


Figure 4: Acton Memorial Library BAU Thermal Profile

The predicted energy use, carbon footprint and utility costs for the Acton Memorial Library BAU case today (2022) are summarized below in Table 8, Table 9 and Table 10.

Table 8: Acton Memorial Library BAU HVAC System Energy Consumption (2022)

	BAU System
Electric Heating/Cooling (KWH/yr)	102,296
Natural Gas Heating (Therm/yr)	25,094
TOTAL Heating/Cooling Energy (MBTU/yr)	2,858,430

Table 9: Acton Memorial Library BAU HVAC System Utility Costs (2022)

	BAU System
Electric Heating/Cooling Utility ($/yr)	$19,436
Natural Gas Heating Utility ($/yr)	$28,105
TOTAL Heating/Cooling Utility ($/yr)	$47,541

Table 10: Acton Memorial Library BAU HVAC System GHG Emissions (2022)

	BAU System
Electric Heating/Cooling (MTCO2e/yr)	31
Natural Gas Heating (MTCO2e/yr)	133
TOTAL Heating/Cooling (MTCO2e/yr)	164

Public Safety Facility

The annual heating and cooling load profile for the Public Safety Facility BAU case is included below in Figure 5.

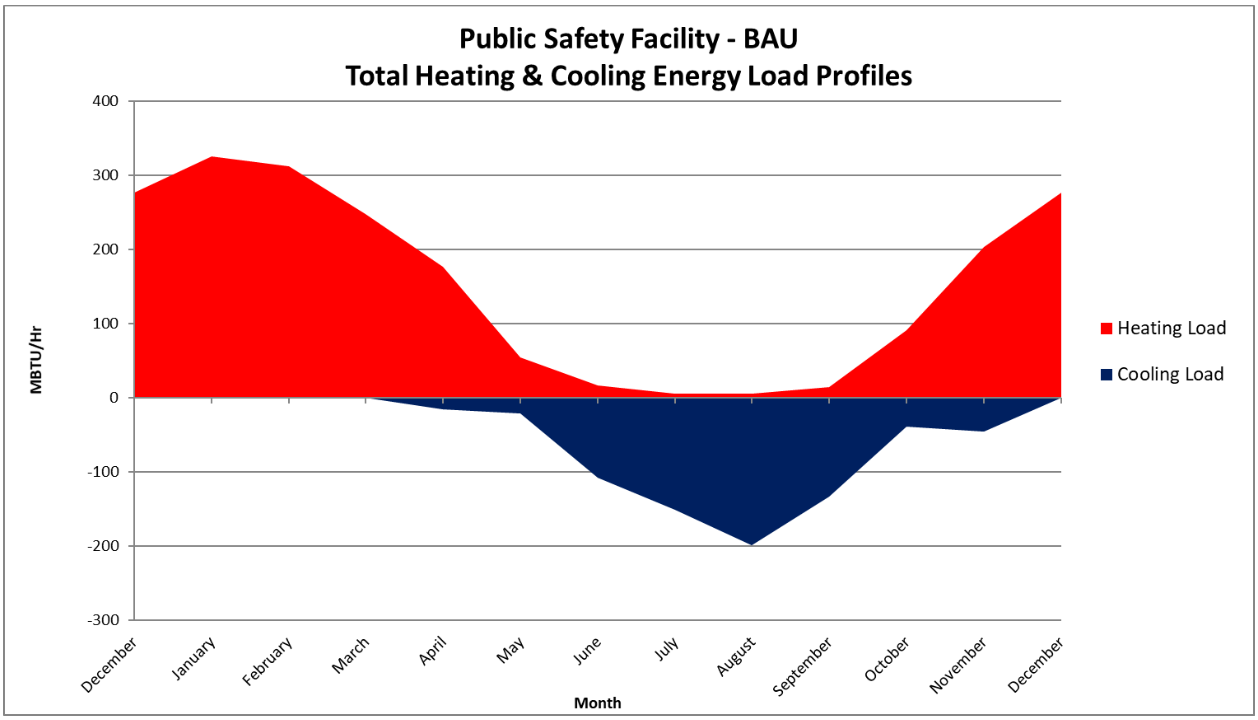


Figure 5: Public Safety Facility BAU Thermal Profile

The predicted energy use, carbon footprint and utility costs for the Public Safety Facility BAU case today (2022) are summarized below in Table 11, Table 12 and Table 13.

Table 11: Public Safety Facility BAU HVAC System Energy Consumption (2022)

	BAU System
Electric Heating/Cooling (KWH/yr)	64,171
Natural Gas Heating (Therm/yr)	19,704
TOTAL Heating/Cooling Energy (MBTU/yr)	2,189,346

Table 12: Public Safety Facility BAU HVAC System Utility Costs (2022)

	BAU System
Electric Heating/Cooling Utility ($/yr)	$12,128
Natural Gas Heating Utility ($/yr)	$22,857
TOTAL Heating/Cooling Utility ($/yr)	$34,985

Table 13: Public Safety Facility BAU HVAC System GHG Emissions (2022)

	BAU System
Electric Heating/Cooling (MTCO2e/yr)	19
Natural Gas Heating (MTCO2e/yr)	105
TOTAL Heating/Cooling (MTCO2e/yr)	124

Acton Boxborough Regional High School (ABRHS)

The annual heating and cooling load profile for the ABRHS BAU case is included below in Figure 6.

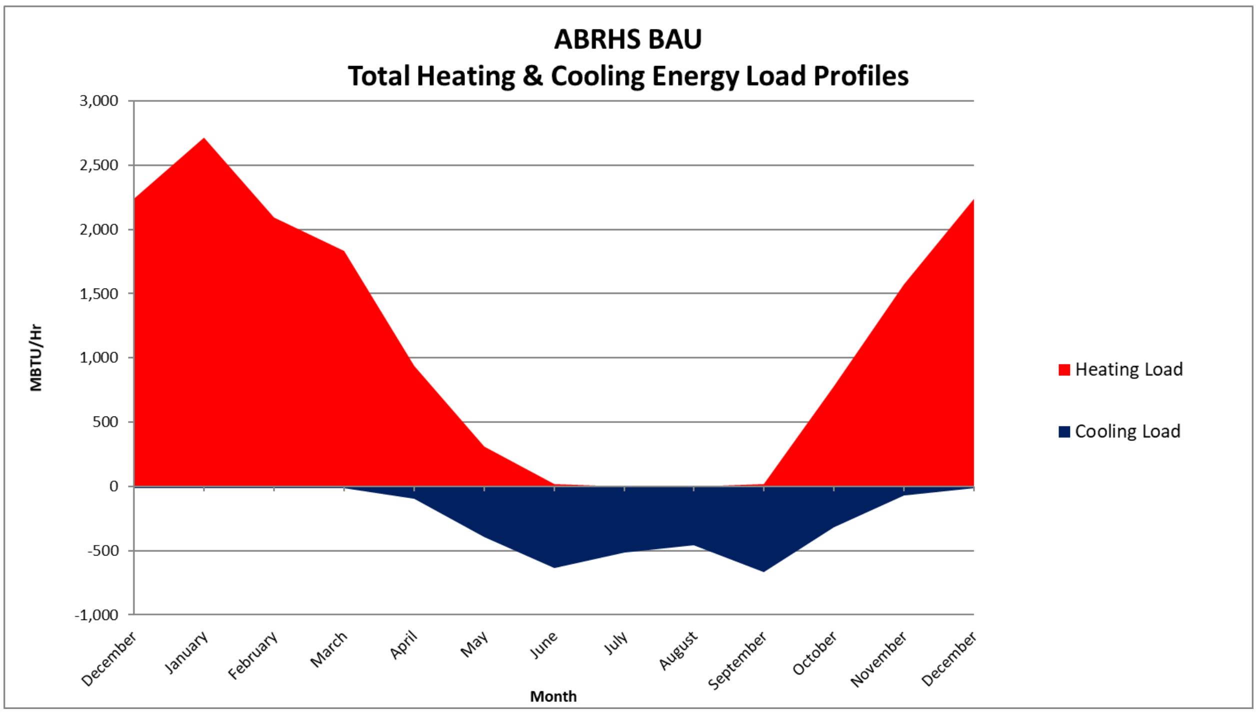


Figure 6: ABRHS BAU Thermal Profile

The predicted energy use, carbon footprint and utility costs for the ABRHS BAU case today (2022) are summarized below in Table 14, Table 15 and Table 16.

Table 14: ABRHS BAU HVAC System Energy Consumption (2022)

	BAU System
Electric Heating/Cooling (KWH/yr)	328,485
Natural Gas Heating (Therm/yr)	110,923
TOTAL Heating/Cooling Energy (MBTU/yr)	12,213,090

Table 15: ABRHS BAU HVAC System Utility Costs (2022)

	BAU System
Electric Heating/Cooling Utility ($/yr)	$56,171
Natural Gas Heating Utility ($/yr)	$123,125
TOTAL Heating/Cooling Utility ($/yr)	$179,295

Table 16: ABRHS BAU HVAC System GHG Emissions (2022)

	BAU System
Electric Heating/Cooling (MTCO2e/yr)	98
Natural Gas Heating (MTCO2e/yr)	589
TOTAL Heating/Cooling (MTCO2e/yr)	687

RJ Grey

The annual heating and cooling load profile for the RJ Grey BAU case is included below in Figure 7.

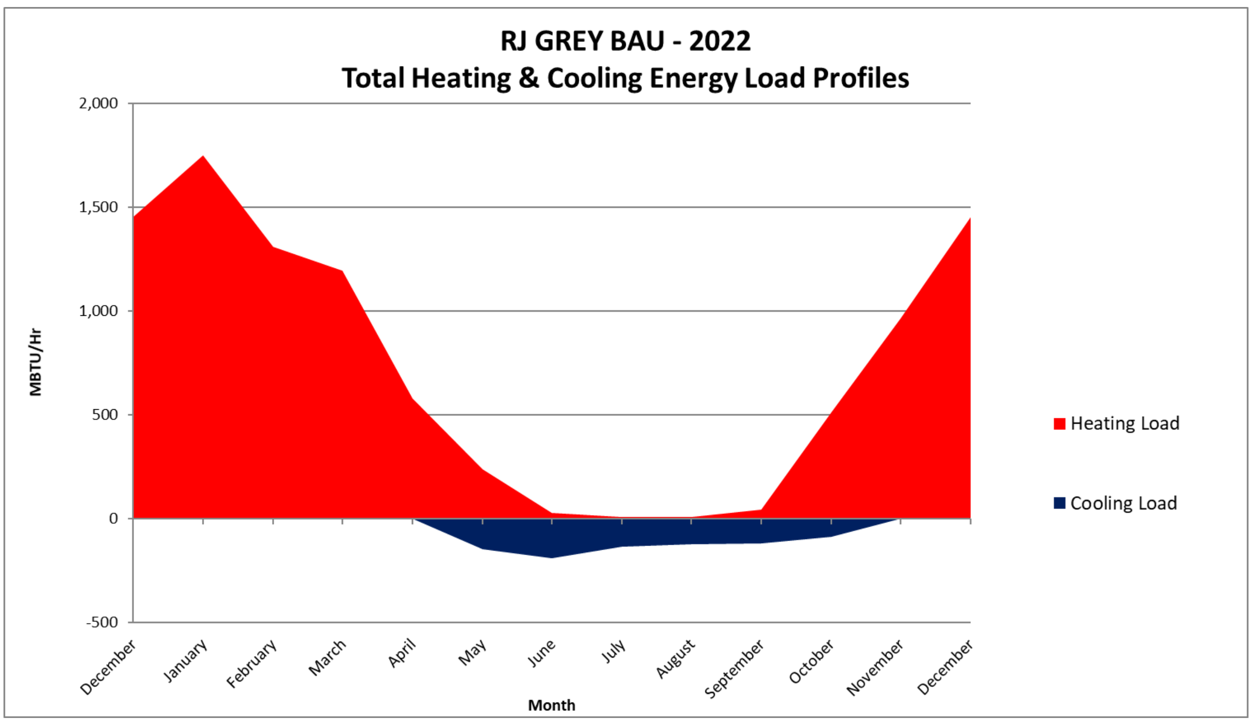


Figure 7: RJ Grey BAU Thermal Profile

The predicted energy use, carbon footprint and utility costs for the RJ Grey BAU case today (2022) are summarized below in Table 17, Table 18 and Table 19.

Table 17: RJ Grey BAU HVAC System Energy Consumption (2022)

	BAU System
Electric Heating/Cooling (KWH/yr)	88,161
Natural Gas Heating (Therm/yr)	73,315
TOTAL Heating/Cooling Energy (MBTU/yr)	7,632,264

Table 18: RJ Grey BAU HVAC System Utility Costs (2022)

	BAU System
Electric Heating/Cooling Utility ($/yr)	$15,076
Natural Gas Heating Utility ($/yr)	$81,379
TOTAL Heating/Cooling Utility ($/yr)	$96,455

Table 19: RJ Grey BAU HVAC System GHG Emissions (2022)

	BAU System
Electric Heating/Cooling (MTCO2e/yr)	26
Natural Gas Heating (MTCO2e/yr)	389
TOTAL Heating/Cooling (MTCO2e/yr)	415

Parker Damon Building

The annual heating and cooling load profile for the Parker Damon Building BAU case is included below in Figure 8.

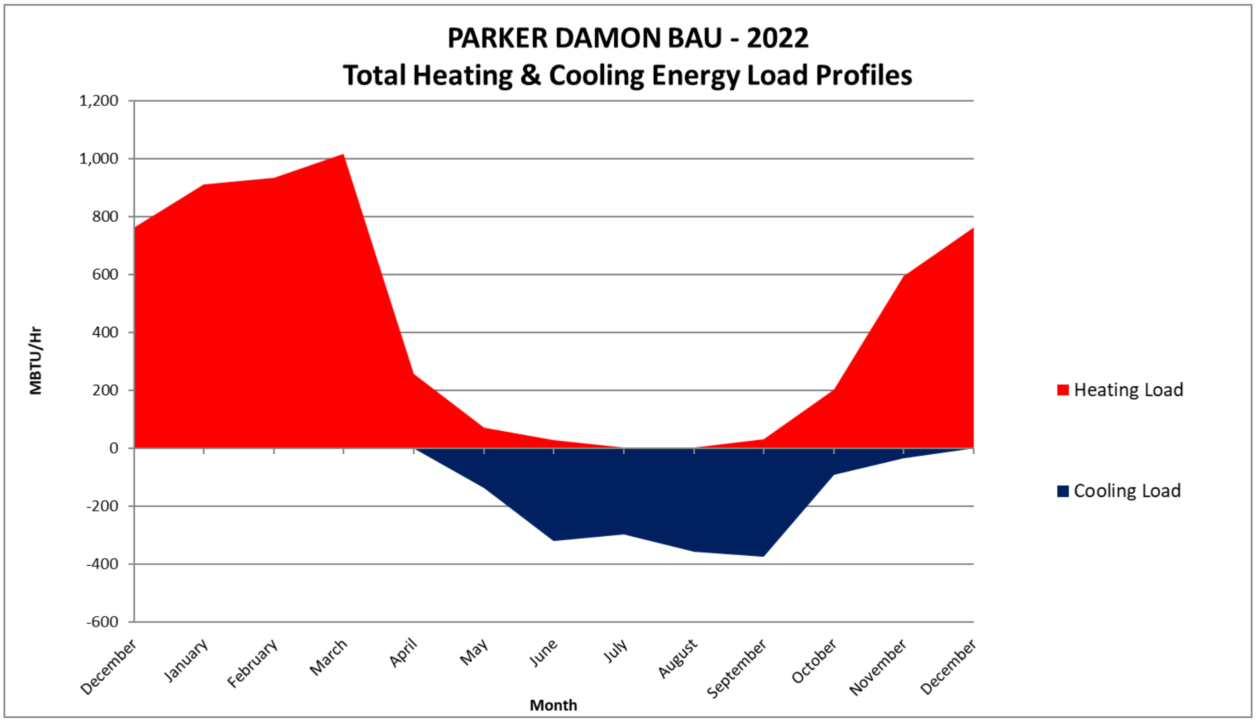


Figure 8: Parker Damon Building BAU Thermal Profile

The predicted energy use, carbon footprint and utility costs for the Parker Damon Building BAU case today (2022) are summarized below in Table 20, Table 21 and Table 22.

Table 20: Parker Damon Building BAU HVAC System Energy Consumption (2022)

	BAU System
Electric Heating/Cooling (KWH/yr)	150,017
Natural Gas Heating (Therm/yr)	43,340
TOTAL Heating/Cooling Energy (MBTU/yr)	4,845,888

Table 21: Parker Damon Building BAU HVAC System Utility Costs (2022)

	BAU System
Electric Heating/Cooling Utility ($/yr)	$25,653
Natural Gas Heating Utility ($/yr)	$48,108
TOTAL Heating/Cooling Utility ($/yr)	$73,761

Table 22: Parker Damon Building HVAC System GHG Emissions (2022)

	BAU System
Electric Heating/Cooling (MTCO2e/yr)	45
Natural Gas Heating (MTCO2e/yr)	230
TOTAL Heating/Cooling (MTCO2e/yr)	275

Administration Building

The annual heating and cooling load profile for the Administration Building BAU case is included below in Figure 9.

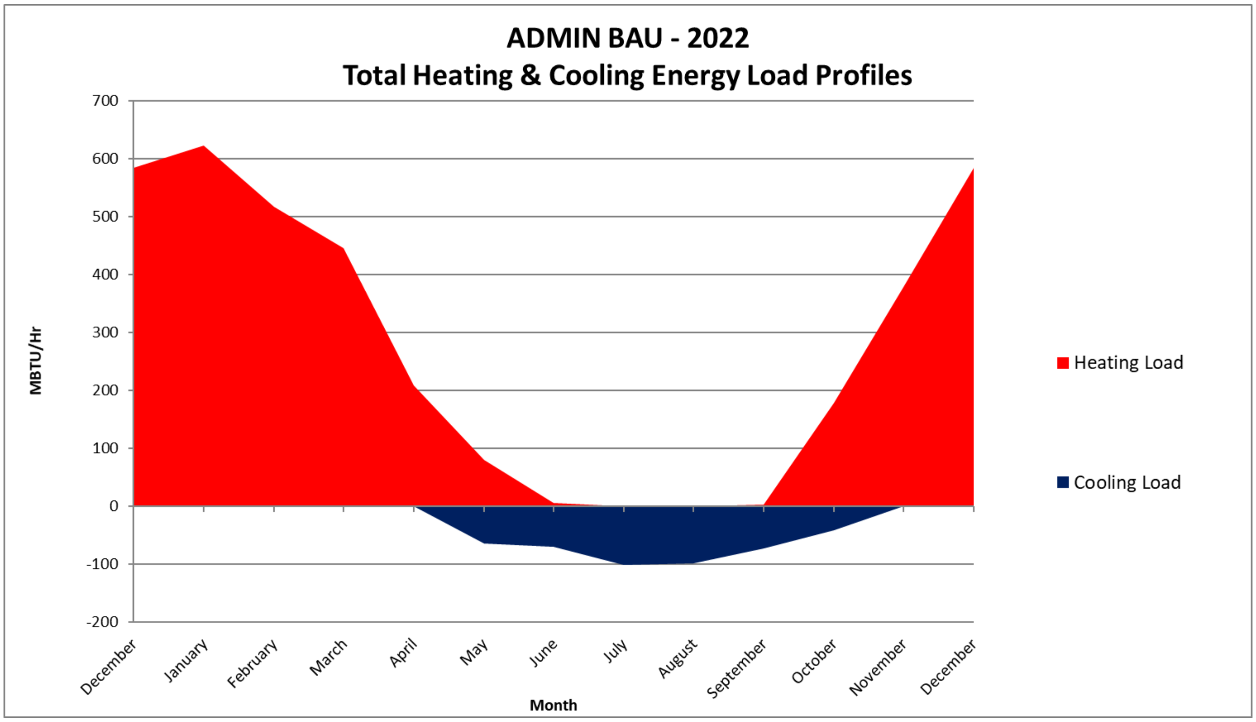


Figure 9: Administration Building BAU Thermal Profile

The predicted energy use, carbon footprint and utility costs for the Administration Building BAU case today (2022) are summarized below in Table 23, Table 24 and Table 25.

Table 23: Administration Building BAU HVAC System Energy Consumption (2022)

	BAU System
Electric Heating/Cooling (KWH/yr)	41,730
Natural Gas Heating (Therm/yr)	23,430
TOTAL Heating/Cooling Energy (MBTU/yr)	2,485,415

Table 24: Administration Building BAU HVAC System Utility Costs (2022)

	BAU System
Electric Heating/Cooling Utility ($/yr)	$7,136
Natural Gas Heating Utility ($/yr)	$26,008
TOTAL Heating/Cooling Utility ($/yr)	$33,144

Table 25: Administration Building BAU HVAC System GHG Emissions (2022)

	BAU System
Electric Heating/Cooling (MTCO2e/yr)	12
Natural Gas Heating (MTCO2e/yr)	124
TOTAL Heating/Cooling (MTCO2e/yr)	137

Massachusetts Electrical Grid GHG Emissions Reductions

Massachusetts is committed to providing 100% carbon-free electricity by 2050, eliminating all carbon emissions associated with purchased electricity after 2050[i]. The Massachusetts Department of Energy Resources (DOER) has provided electricity GHG emission factors specific to Massachusetts, included below in Figure 10 and in Table 4 above. The projected Massachusetts grid emissions factors beyond 2022 included in Figure 10 are estimates based on the 2022 electricity emission factor of 0.658 and an assumed electricity emissions factor of zero in 2050. While the actual emissions factor reductions may not be linear, this straight-line projection in Figure 10 accounts for the assumed emissions reduction commitments by Massachusetts. These emissions factors are used to model predicted GHG emissions associated with purchased electricity. The declining electric grid GHG emissions factor contributes to the electrical carbon emissions reduction for this Electrification Roadmap.

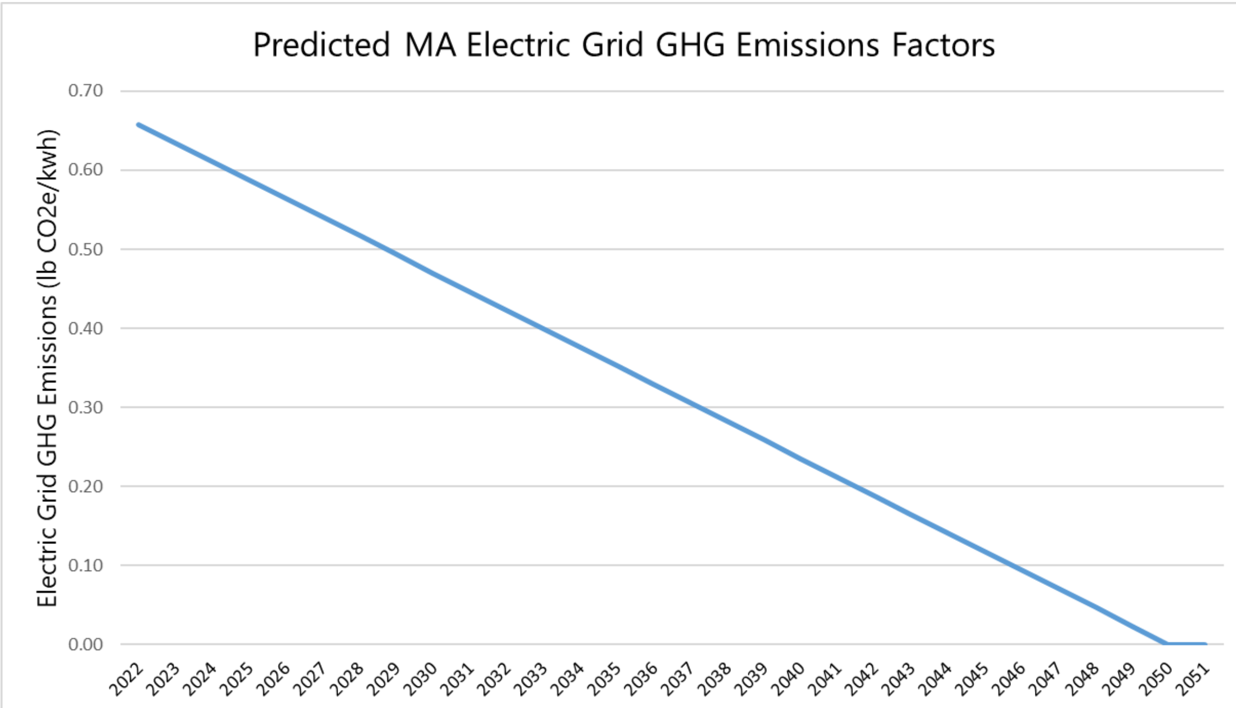


Figure 10: Expected Massachusetts Grid Emissions Factors Through 2050

Estimated Maintenance Costs

Maintenance costs for the BAU case were based on maintenance budgets received from the Town of Acton and ABRSD's respective facilities teams. Maintenance costs for the town buildings were assumed to be an average of each building's recorded maintenance from 2017 to 2021. Table 26 shows the estimated annual BAU maintenance cost for the town buildings.

Table 26: Town of Acton Estimated Annual BAU Maintenance Cost

Building	Estimated Annual BAU Maintenance Cost
Acton Town Hall	$16,211
Acton Memorial Library	$26,341
Public Safety Facility	$34,863
Total	$77,415

Maintenance costs for the school district buildings were based on an overall preventative maintenance budget of $98,000 provided by ABRSD. The maintenance costs were provided without an individual building breakdown, so the maintenance budget was allocated to each building based on building area. Table 27 shows the estimated annual BAU maintenance cost for the school district buildings.

Table 27: ABRSD Estimated Annual BAU Maintenance Cost

Building	Estimated Annual BAU Maintenance Cost
ABRHS	$53,900
RJ Grey	$19,600
Parker Damon	$19,600
Administration Building	$4,900
Total	$98,000

Additional details on the BAU maintenance costs, including a summary of maintenance costs by year and equipment type are included in Appendix B.

Capital Expenditures

Capital expenditures for the BAU case include the replacement of existing heating and cooling systems that have already exceeded their expected service life or would exceed their expected service life during the study period. Replacement of existing heating and cooling systems include all central equipment, such as gas-fired boilers, as well as all terminal devices, such as finned tube radiators, reheat coils and FCUs. These replacement costs for existing heating and cooling systems provide a baseline cost comparison for the electrification scenarios. The BAU capital expenditures assume replacement costs for equipment only and does not include upgrades or improvements and would maintain the existing HVAC systems. A summary of the HVAC replacement costs by year are provided in Table 28 and Table 29 below. All dollar amounts are in 2022 dollars. Additional details on the heating and cooling systems replacement costs are provided in Appendix A. Cost estimates for this study were developed using RS Means cost data, direct input from manufacturers and prior experience on energy master planning projects. RS Means is a database of construction cost estimating information that accounts for location and is updated annually.

Through proactive preventative maintenance, the ABRSD is able to extend equipment's service life beyond ASHRAE guidelines by an additional five years. The BAU capital costs for the ABRSD buildings in Table 29 below incorporate this extended equipment service life.

Table 28: Town of Acton BAU Capital Cost Summary by Year

Year	Memorial Library	Town Hall	Public Safety Facility	Total
2022	-	-	$280,506	$280,506
2023	-	-	-	-
2024	-	-	-	-
2025	-	-	-	-
2026	-	-	-	-
2027	-	-	-	-
2028	-	-	-	-
2029	-	$19,289	-	$19,289
2030	-	-	$54,459	$54,459
2031	-	-	-	-
2032	-	-	-	-
2033	$313,844	-	-	$313,844
2034	-	-	-	-
2035	-	-	-	-
2036	-	-	-	-
2037	-	-	$280,506	$280,506
2038	-	$127,600	-	$127,600
2039	-	-	-	-
2040	-	-	-	-
2041	-	-	-	-
2042	$61,709	-	-	$61,709
2043	-	-	-	-
2044	-	$19,289	-	$19,289
2045	-	-	-	-
2046	-	-	-	-
2047	-	-	-	-
2048	$313,844	-	-	$313,844
2049	-	-	-	-
2050	-	-	-	-
2051	-	-	-	-
Total	$689,397	$166,177	$615,471	**$1,471,045**

Table 29: ABRSD BAU Capital Cost Summary by Year

Year	Administration Building	Parker Damon	RJ Grey	ABRHS	Total
2022	$24,409	$403,074	$167,169	$769,225	$1,363,877
2023	-	-	-	-	-
2024	-	-	-	-	-
2025	-	-	$27,460	$1,784,602	$1,812,062
2026	-	$1,333,891	-	-	$1,333,891
2027	$61,538	-	$536,138	-	$597,676
2028	-	-	-	-	-
2029	$24,409	-	-	-	$24,409
2030	$57,866	-	-	$791,881	$849,747
2031	-	-	-	-	-
2032	-	-	$27,460	-	$27,460
2033	-	-	-	-	-
2034	-	-	-	-	-
2035	-	-	-	$578,206	$578,206
2036	$24,409	$109,080	$246,836	-	$380,325
2037	-	-	$72,720	-	$72,720
2038	-	-	-	-	-
2039	-	-	$27,460	-	$27,460
2040	-	-	-	$136,350	$136,350
2041	-	-	-	-	-
2042	-	$403,074	$167,169	$769,225	$1,339,468
2043	-	-	-	-	-
2044	-	-	$246,836	-	$246,836
2045	-	$170,285	-	$1,784,602	$1,954,887
2046	-	-	-	-	-
2047	$61,538	-	-	-	$61,538
2048	-	-	-	-	-
2049	$108,918	-	-	-	$108,918
2050	$57,866	-	-	-	$57,866
2051	-	$1,333,891	-	-	$1,333,891
Total	$420,953	$3,753,295	$1,519,248	$6,614,092	**$12,307,589**

Energy Conservation Measures

Energy Conservation Measures (ECMs) include building upgrades, retrofits and repairs that can be implemented to improve energy efficiency and reduce operation and maintenance costs. ECMs can include lighting system retrofits, façade air sealing, HVAC system and controls upgrades, and retro-commissioning. Both the Town of Acton and the ABRSD have made reductions in their building energy use by investing in energy efficiency benchmarking initiatives and energy audits.

Lighting / lighting control system upgrades, façade air sealing and adding variable speed controllers to pumps and fan are ECMs that often provide a relatively quick payback on initial investment. More involved HVAC system and controls upgrades, such as adding energy recovery systems or new building controls systems, and envelope improvements, such as window replacements or adding exterior insulation, can be more cost effective when planned during a major renovation. A summary of potential ECMs by building is included in Table 30 below. These recommendations are based on a review of available as built documentation, energy audits and building walk throughs with facilities staff.

Table 30: Potential ECMs by Building

Building	ECM Opportunity
Acton Memorial Library	Energy Recovery (RTUs)
Acton Town Hall	Energy Recovery (New ERVs)
Public Safety Facility	Energy Recovery (AHUs)
Acton-Boxborough Regional High School	Energy Recovery (RTUs) Kitchen Ventilation / Exhaust Controls (Variable Speed) Retro-Commissioning (Jackson Church RTU replacements) HVAC Controls Upgrades
Administration Building	Envelope improvements (Window Replacement, Insulation, Roof replacement w/ added insulation) Energy Recovery (AHUs) HVAC Controls Upgrades
Parker Damon	Energy Recovery (RTUs) Kitchen Ventilation / Exhaust Controls (Variable Speed) HVAC Controls Upgrades
RJ Grey Junior High	Lighting Upgrades Energy Recovery (RTUs) Kitchen Ventilation / Exhaust Controls (Variable Speed) Façade Air Sealing

Onsite Photovoltaic (PV)

ABRSD has existing PV arrays installed at the High School (104 kW) and RJ Grey Junior High (104 kW). Acton is planning to install a 287 kW array at the Public Safety Facility. The electricity generated from onsite PV installations will directly reduce the amount of electricity that would otherwise be purchased from the grid. Additional onsite renewable electricity generation will reduce purchased electricity. Both Acton and ABRSD will continue plans to install onsite PV via power purchase agreements (PPA). While these projects will not likely retain the renewable energy credits associated with the onsite renewable generation, they will still provide the benefit of reduced annual energy costs and generate clean renewable electricity. Onsite PV potential is evaluated for the following buildings:

- Administration Building
- Parker Damon
- Acton Town Hall
- Acton Memorial Library
- Public Safety Facility

Administration Building

Reviewing the existing roof, including existing roof mounted equipment, one 86 kW, 5,370 SF PV system of roof mounted arrays could likely be installed for a possible production of 107,000 kWh/year. Figure 11 shows the possible location of the array on the building roof.

Figure 11: Administration Building PV Layout

Parker Damon

Reviewing the existing roof, including existing roof mounted equipment, four PV systems of roof mounted arrays could likely be installed as follows:

- System 1: 56 kW system of 3,500 SF for a possible production of 70,000 kWh/year
- System 2: 56 kW system of 3,500 SF for a possible production of 70,000 kWh/year
- System 3: 96 kW system of 6,000 SF for a possible production of 120,000 kWh/year
- System 4: 96 kW system of 6,000 SF for a possible production of 120,000 kWh/year

Figure 12 shows the possible array locations on the roof of the Parker Damon building.

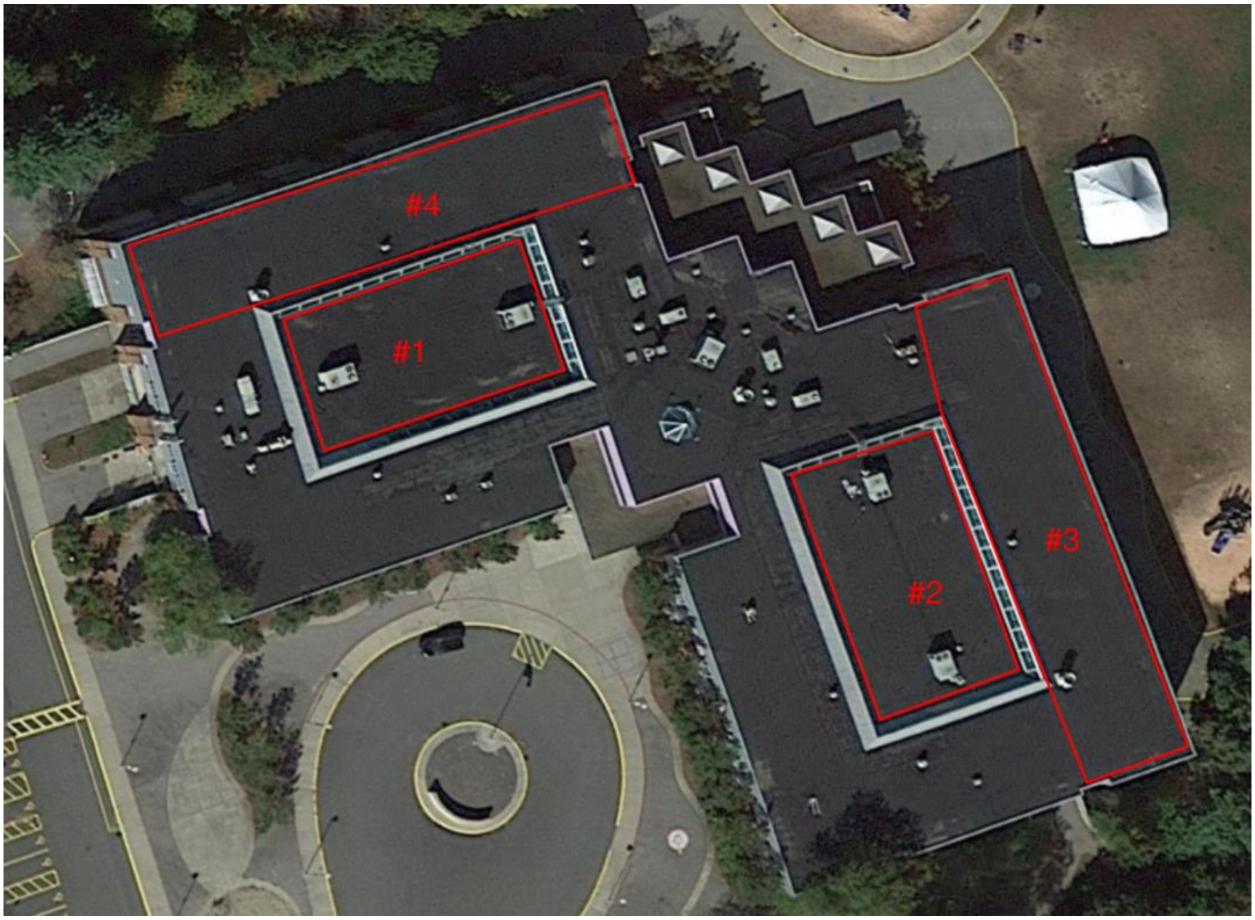


Figure 12: Parker Damon PV Layout

Acton Town Hall

The building is on the historic register and there currently is no roof space or available ground space for solar panels. There is a possibility of adding a small 18.24 kW array of 1,140 SF for a possible production of 22,800 kWh/year, located on the southwest facing sloped roof, however this would likely impact the historic characteristic of the building. Figure 13 shows the possible location of the array on the building roof. Due to the existing slate roof and historic registration, a ground mounted PV array might be a better option for the Town Hall.

Figure 13: Acton Town Hall PV Layout

Acton Memorial Library

Reviewing the existing roof, including existing roof mounted equipment, one 40 kW, 2,500 SF PV system of roof mounted arrays could likely be installed for a possible production of 50,000 kWh/year. Figure 14 shows the possible location of the array on the building roof.

Figure 14: Acton Memorial Library PV Layout

Public Safety Facility

Reviewing the existing roof, including existing roof mounted equipment, the roof was deemed not a viable option for PV at the Public Safety Facility. Instead, a 287 kW PV canopy system located over the parking lot could be installed for a possible production of 309,400 kWh/year, which is equivalent to roughly 81% of the building's annual electricity consumption. Figure 15 shows the possible location of the PV canopy system over the parking lot. The Public Safety Facility is pursuing a ground mounted PV array through Solect, a solar development company.

Figure 15: Public Safety Facility PV Layout

Electrification Options

Summary of Electrification Solutions Considered

Low-temperature Hot Water (LTHW) Conversion

Low temperature hot water (LTHW) conversion includes converting existing high temperature hot water (HTHW) heating systems to LTHW. LTHW will be distributed within buildings at 120-130°F, lower than standard HTHW systems that distribute at 160-180°F. Benefits of the lower operating temperature include reduced heat losses in distribution, lower operation and maintenance costs, improved safety, and a wider array of electrified energy sources available for generation when compared to steam or HTHW. All buildings utilizing HTHW will require a building conversion to replace existing heating systems with new low temperature compatible equipment.

Air Source Heat Pumps

An Air Source Heat Pump (ASHP) is a heating and cooling system that transfers heat to and from the outdoor air to generate CHW for cooling and LTHW for heating, which can be used as part of both forced air and radiant HVAC systems, as ASHPs can generate LTHW more efficiently than HTHW. This technology is best suited for a LTHW system rather than a steam system or HTHW system. ASHPs are installed outdoors and are less efficient than GSHPs. ASHPs have a cheaper installed cost compared to Ground Source Heat Pumps (GSHP) systems. ASHP technology is evolving, allowing a broader application across a wider market, with the potential to bring down capital investment. ASHPs are capable of generating LTHW even when outdoor temperatures are below freezing.

Onsite Solar Thermal

Onsite solar thermal systems include solar hot water panel arrays that produce hot water to be distributed to the building for heating. Solar hot water panels can be installed on roofs, parking structures, and can also be surface mounted at grade. In addition to the solar hot water panels, new distribution pumps and piping will be required to connect the panels to the building hot water distribution systems. The solar thermal system would reduce the need for fossil fuel combustion and would produce hot water year-round. For solar thermal arrays to be effective, buildings with these systems need a year-round heating load.

Solutions Considered but Not Modeled

Ground Source Heat Pump (GSHP)

A Geothermal Heat Pump or Ground-Source Heat Pump (GSHP) system is a heating and cooling system that transfers heat to and from the ground. GSHPs use the relatively stable temperatures of the earth as a heat source in the winter and as a heat sink in the summer. A ground source heating and cooling system consists of water source heat pumps and heat recovery chillers coupled with a geothermal bore field heat exchanger used for heating and cooling. This technology is best suited for a LTHW system rather than the current HTHW systems as heat pumps and heat recovery chillers generate LTHW more efficiently than HTHW. GSHP systems can be used in central plant or standalone, individual building applications. As the existing buildings are currently all standalone (not part of a campus distribution system) and due to the high capital costs, a GSHP system is not being modeled as an energy solution for this study. For reference, Appendix D includes an energy plant cost breakdown for ABRHS with a GSHP system.

Renewable Fuel Oil (RFO) Boiler

Renewable Fuel Oil RFO is a cellulosic biofuel produced through refining wood waste collected from commercial forestry operations. RFO offers reduced GHG emissions over traditional heating oils, such as diesel. RFO boilers can be utilized to meet a portion of a building heating load not met by GSHP and ASHP systems, as well as provide heating system redundancy requirements. New RFO boilers and new fuel storage system would be integrated into a new LTHW distribution system and located in the existing boiler plant at a building, replacing existing natural gas boilers. There are open questions about the carbon accounting of all biofuels, and while this technology offers carbon reduction over petroleum-based fossil fuels, it is still a combustion technology and does not meet the electrification goals of this study. Alternative biogenic, renewable fuels might be available in cost effective, sufficient supply in the future.

Wastewater Heat Recovery (HR)

Wastewater Heat Recovery (HR) is the process of using wastewater as a heat sink or heat source for a water-to-water heat recovery chiller / heat pump system. Wastewater is diverted from the sewer line and heat is extracted from or rejected to the wastewater and is then returned to the sewer line. Wastewater HR systems can be utilized at the campus level or at the building level. At a campus level, the wastewater HR system can augment the ground source heat exchange system by reducing the number of boreholes needed, as wastewater HR systems can be less capital-intensive than geothermal heat exchangers. For individual buildings, wastewater HR can be utilized to generate domestic hot water (DHW) for buildings with high domestic hot water usage. Coordination with the local wastewater treatment facility is required to ensure that heat transfer to and from the wastewater stream does not negatively impact wastewater treatment operations at the treatment facility. As geothermal and campus approaches are not being considered, wastewater HR is not being modeled as an energy solution.

Recommended Electrification Options – Town of Acton

The electrification implementation timeline for the Town of Acton buildings is included below in Figure 16. This implementation timeline includes all three building conversions to electrified HVAC systems by 2030, in alignment with the Town of Acton Climate Emergency Declaration goal of net zero emissions by 2030. The Public Safety Facility has been selected first for electrification as input from the Town of Acton Facilities team indicates that the existing HVAC systems will soon require replacement and the building operations are critical to the Town of Acton. The implementation schedule below is ambitious in terms of planning, funding, and construction; however, it will accelerate the impact on the Town's energy use and carbon emissions.

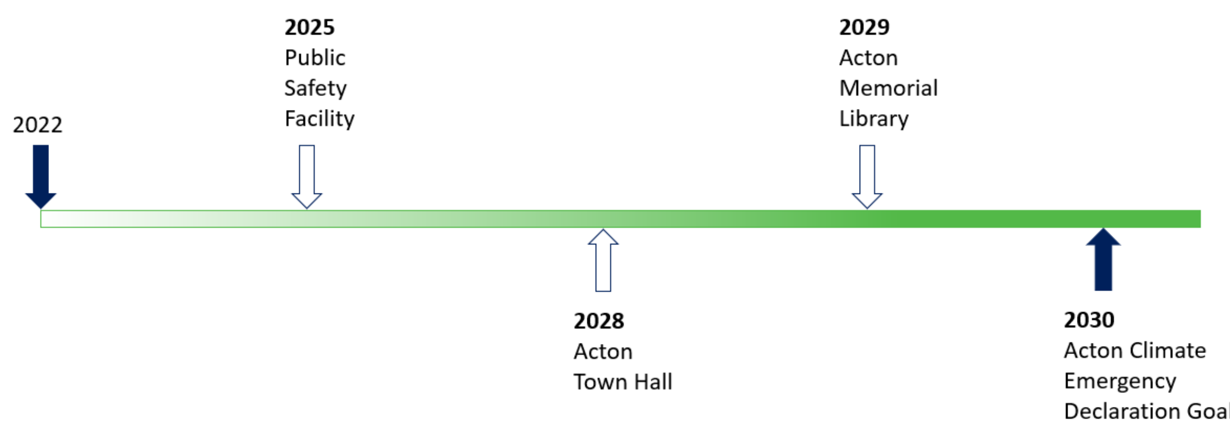


Figure 16: Town of Acton Implementation Timeline

Acton Town Hall

Overview

To achieve the goal of electrification while satisfying the building's heating and cooling loads, the existing natural gas boiler and air-cooled chiller will be replaced by two ASHPs located on grade in or near the existing equipment enclosure. The ASHP capacity was determined by sizing the ASHPs to cover the building's peak heating load of 450 MBH. Since ASHPs have a higher cooling COP than heating COP, a unit with this heating capacity will have a higher cooling capacity of 612 MBH (47 Tons), which will satisfy the building's peak cooling load. Due to the Town Hall's similar heating and cooling peak loads of 450 MBH and 516 MBH, respectively, the building can be fully heated and cooled by the ASHP system without a need for additional systems for peak heating and cooling conditions. To avoid losing all heating or cooling due to an equipment failure, two ASHPs sized at 75% of the building's peak heating load will be installed, resulting in total heating and cooling capacities of 720 MBH and 900 MBH (75 Tons), respectively. Figure 17 below shows the Town Hall's monthly average load profile over the course of a year.

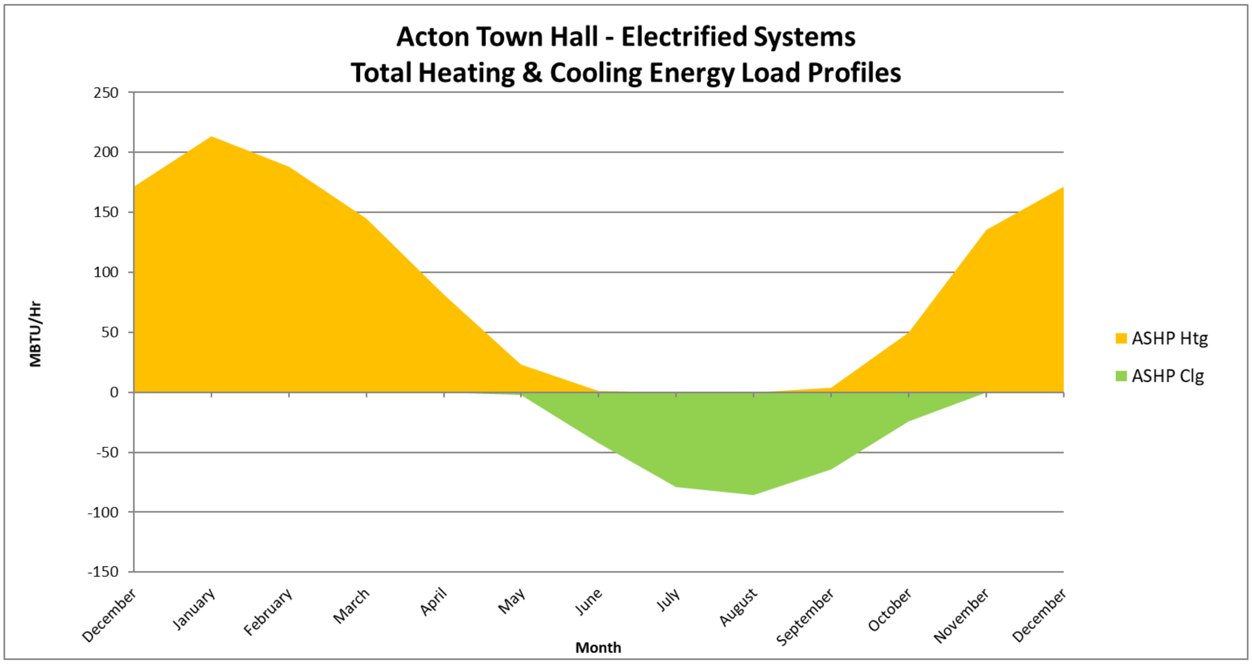


Figure 17: Acton Town Hall Electrified Annual Heating & Cooling Load Profile

Of the major existing HVAC components serving the building, the natural gas boiler is expected to reach the end of its service life first, in 2038. To maximize the usefulness of the existing equipment, it was recommended that the Town Hall be converted to the ASHP system in 2038. However, in order to reach the Acton Climate Emergency Declaration Goal of fully electrifying all municipal buildings by 2030, the Electrification Roadmap timeline includes this building being fully converted in 2028.

Electrical Infrastructure

The proposed central energy plant mechanical work includes removal of the existing chiller and the installation of two 53 kW ASHPs and two 3 HP CHW pumps (run/standby).

Disconnect and remove existing Chiller and associated circuitry completely.

Given the age of the existing electrical equipment it is recommended to replace the existing distribution board "MDP" with a new service rated distribution board of matching size and breaker configuration.

The existing 50 kW generator and associated transfer switch are inadequate and shall be disconnected and removed completely and replaced with a new 100 kW generator with a 300 A breaker and 400 A transfer switch.

Existing panel "ELG" to be disconnected, removed, and replaced maintaining existing circuitry by necessary means for reconnection to new panel in same location. New panel "ELG" to be a 400 A, 3-phase, 4-wire, 60 circuit panelboard with a 300 A main breaker. Existing breakers to be matched on a one-for-one basis. Reconnect by necessary means existing circuitry to new breakers. Provide two additional 150 A, 3-phase breakers for the two new heat pump and two 20 A, 3-phase breakers for new CHW pumps.

"MDP": Provide breakers of matching size for elevator, Panel "LLG," "PL1," "PL2," "PLG," Meeting Hall Panel, and car charging stations. Provide one 300 A, 3-phase breaker to feed new 400 A transfer switch, and two 150 A, 3-phase breakers for new heat pumps.

Provide complete connections to new mechanical equipment.

Performance: Energy, Carbon, Utility Cost

The effects of the conversion to a fully electrified system on the building's energy use, utility costs, and GHG emissions are outlined in Table 31, Table 32 and Table 33.

Table 31: Acton Town Hall HVAC System Energy Consumption Comparison (2030)

	BAU System	Electrified System	Delta	% Change
Electric Heating/Cooling (KWH/yr)	26,922	110,231	-83,308	309.4%
Natural Gas Heating (Therm/yr)	11,536	0	11,536	-100.0%
TOTAL Heating/Cooling Energy (MBTU/yr)	1,245,485	376,107	869,378	-69.8%

Table 32: Acton Town Hall HVAC System Utility Cost Comparison (2030)

	BAU System	Electrified System	Delta	% Change
Electric Heating/Cooling Utility ($/yr)	$5,573	$22,818	-$17,245	309.4%
Natural Gas Heating Utility ($/yr)	$13,728	$0	$13,728	-100.0%
TOTAL Heating/Cooling Utility ($/yr)	$19,301	$22,818	-$3,517	18.2%

Table 33: Acton Town Hall HVAC System GHG Emission Comparison (2030)

	BAU System	Electrified System	Delta	% Change
Electric Heating/Cooling (MTCO2e/yr)	6	23	-18	309.4%
Natural Gas Heating (MTCO2e/yr)	61	0	61	-100.0%
TOTAL Heating/Cooling (MTCO2e/yr)	67	23	43	-64.9%

Converting Town Hall to a fully electrified building (2030) decreases overall energy use by 69.8%, while increasing electricity use by 309.4%. GHG emissions are reduced by 64.9%. The annual utility cost increases by 18.2%.

Acton Memorial Library

Overview

To achieve the goal of electrification while satisfying the building's heating and cooling loads, the existing natural gas boiler and RTUs with DX cooling and natural gas heating will be replaced by two ASHPs as well as a 680 MBH electric boiler to handle peak heating loads. The ASHPs will be located on grade in a new equipment enclosure or potentially located on the roof pending structural review. The ASHP capacity was determined by sizing the ASHPs to cover the building's peak cooling load of 900 MBH (75 Tons). Since ASHPs have a higher cooling COP than heating COP, a unit with this cooling capacity will have a lower heating capacity of 720 MBH. Due to the Memorial Library's higher peak heating load of 1,400 MBH compared to its 900 MBH peak cooling load, a supplemental electric boiler was modeled to cover the high peak heating load. To avoid losing all heating or cooling due to an equipment failure, two ASHPs sized at 75% of the building's peak heating load will be installed, resulting in total ASHP heating and cooling capacities of 1,104 MBH and 1,380 MBH (115 Tons), respectively. Figure 18 below shows the Memorial Library's monthly average load profile over the course of a year.

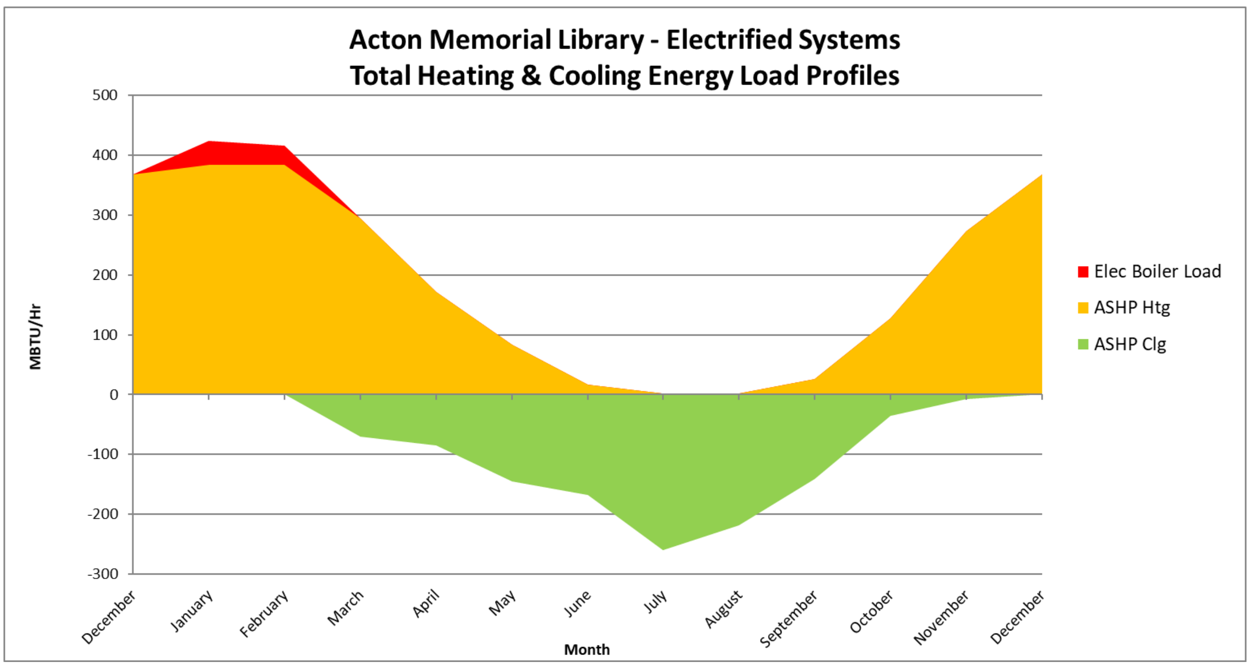


Figure 18: Acton Memorial Library Electrified Annual Heating & Cooling Load Profile

Of the major existing HVAC components serving the building, the natural gas boiler is expected to reach the end of its useful life first, in 2033. To maximize the usefulness of the existing equipment, it was recommended that the library be converted to the fully electrified system in 2033. However, in order to reach the Acton Climate Emergency Declaration Goal of fully electrifying all municipal buildings by 2030, the Electrification Roadmap timeline has this building being fully converted in 2029.

Electrical Infrastructure

The proposed work includes removal of the existing RTUs and the installation of two 79 kW ASHPs, two 3 HP CHW pumps (run/standby) and one 200 kW electric boiler.

Existing 60 kW generator and associated transfer switch are inadequate and shall be disconnected, removed completely, and replaced with a new 125 kW generator with a 300 A breaker for standby, 100 A for life safety and 400 A transfer switch.

Existing panel "LNE-1" to be disconnected, removed, and replaced maintaining existing circuitry by necessary means for reconnection to new panel in same location. New panel "LNE-1" to be a 400 A, 3-phase, 4-wire, 60 circuit panelboard with a 300 A main breaker. Existing breakers to be matched on a one-for-one basis. Reconnect by necessary means existing circuitry to new breakers. Provide two additional 225 A, 3-phase breakers for ASHPs and two 30 A, 3-phase breakers for new CHW pumps.

Disconnect and remove existing RTUs and associated circuitry completely. Maintain breakers as spares. New RTU's to be fed from existing panels/switchboards. Contractor may utilize existing breakers from removal of existing RTU's where feasible.

Provide two 225 A, 3-phase breakers in existing switchboard for power to two new ASHPs, and one 600 A, 3-phase breaker for the new electric boiler. Provide two 40A, 3-phase breakers for RTU's 1 and 2 and two 20A, 3-phase breakers for RTU's 2 and 4. Provide complete connections to new mechanical equipment.

Performance: Energy, Carbon, Utility Cost

The effects of the conversion to a fully electrified system on the building's energy use, utility costs, and GHG emissions are outlined in Table 34, Table 35 and Table 36.

Table 34: Acton Memorial Library HVAC System Energy Consumption Comparison (2030)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling (KWH/yr)	102,296	265,928	-163,632	160.0%
Natural Gas Heating (Therm/yr)	25,094	0	25,094	-100.0%
TOTAL Heating/Cooling Energy (MBTU/yr)	2,858,430	907,345	1,951,085	-68.3%

Table 35: Acton Memorial Library HVAC System Utility Cost Comparison (2030)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling Utility ($/yr)	$19,436	$50,526	-$31,090	160.0%
Natural Gas Heating Utility ($/yr)	$28,105	$0	$28,105	-100.0%
TOTAL Heating/Cooling Utility ($/yr)	$47,541	$50,526	-$2,985	6.3%

Table 36: Acton Memorial Library HVAC System GHG Emission Comparison (2030)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling (MTCO2e/yr)	22	57	-35	160.0%
Natural Gas Heating (MTCO2e/yr)	133	0	133	-100.0%
TOTAL Heating/Cooling (MTCO2e/yr)	155	57	98	-63.4%

Converting Acton Memorial Library to a fully electrified building (2030) decreases overall energy usage by 68.3%, while increasing electricity use by 160.0%. GHG emissions are reduced by 63.4%. The annual utility cost will increase by 6.3%.

Public Safety Facility

Overview

To achieve the goal of electrification while satisfying the building's heating and cooling loads, the existing natural gas boiler and DX cooling will be replaced by two ASHPs located on grade in the existing equipment enclosure. The ASHP capacity was determined by sizing the ASHPs to cover the building's peak heating load of 550 MBH. Since ASHPs have a higher cooling COP than heating COP, a unit with this heating capacity will have a higher cooling capacity of 684 MBH (57 Tons), which will satisfy the building's peak cooling load. Due to PSF's similar heating and cooling peak loads of 550 MBH and 657 MBH, respectively, the building can be fully heated and cooled by the ASHP system without a need for additional systems. To avoid losing all heating or cooling due to an equipment failure, two ASHPs sized at 75% of the building's peak heating load will be installed, resulting in total heating and cooling capacities of 864 MBH and 1,080 MBH (90 Tons), respectively. Figure 19 below shows the Public Safety Facility's monthly average load profile over the course of a year.

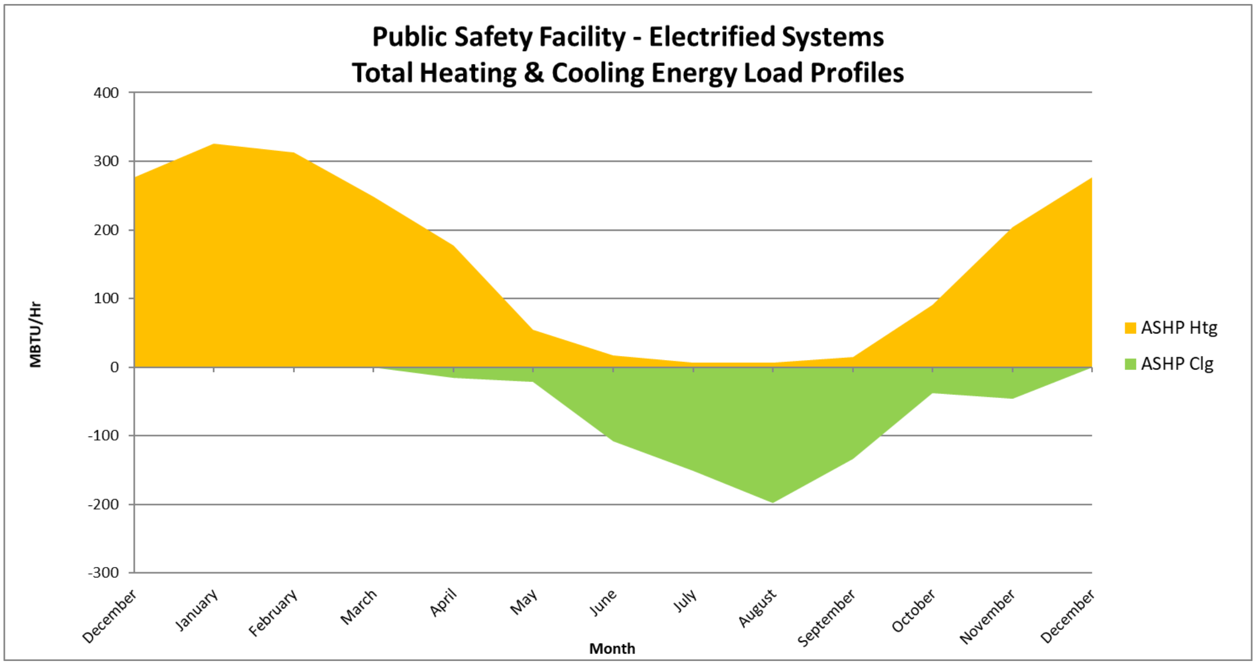


Figure 19: Public Safety Facility Electrified Annual Heating & Cooling Load Profile

Of the major existing HVAC components serving the building, the natural gas boiler is expected to reach the end of its useful life first, in 2039. To maximize the usefulness of the existing equipment, it was recommended that PSF be converted to the ASHP system in 2038. However, as the existing DX cooling systems serving the AHUs are nearing the end of their expected service life and in consideration of the Acton Climate Emergency Declaration Goal of fully electrifying all municipal buildings by 2030, the Electrification Roadmap timeline has this building being fully converted in 2025. This building specifically was moved to the beginning of the timeline because the Town of Acton Facilities team indicated that the existing HVAC systems will require replacement in the near future given their recent need for ongoing maintenance. By 2025, the boiler will be 21 years old, which is older than the Memorial Library's boiler when it broke in 2017, after 19 years of service.

Electrical Infrastructure

The proposed work includes removal of the existing condensing units and the installation of two 63 kW ASHPs and two 5 HP CHW pumps (run/standby).

Disconnect and remove existing condensing units and associated circuitry completely. Maintain breakers as spares.

Due to lack of breaker space in "SB2"and configuration of gear it is recommended to replace "SB2" with a new I-line power distribution panelboard. Disconnect and remove existing switchboard "SB2". Maintain existing circuitry for reconnection to new distribution board "DP-1". Provide breakers to match existing and reconnect by necessary means to new breakers in new distribution board. Provide two additional 175 A, 3-phase breakers for new ASHPs and two 30 A, 3-phase breakers for CHW pumps.

The existing 250 kW generator is inadequate for the current and new loads. Existing 250 kW generator to be disconnected and removed completely and replaced with a new 350 kW, 208/120 V, 3-phase, 4-wire generator.

Provide complete connections to new mechanical equipment.

Performance: Energy, Carbon, Utility Cost

The effects of the conversion to a fully electrified system on the building's energy use, utility costs, and GHG emissions are outlined in Table 37, Table 38 and Table 39.

Table 37: Public Safety Facility HVAC System Energy Consumption Comparison (2030)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling (KWH/yr)	64,171	199,159	-134,988	210.4%
Natural Gas Heating (Therm/yr)	19,704	0	19,704	-100.0%
TOTAL Heating/Cooling Energy (MBTU/yr)	2,189,346	679,530	1,509,815	-69.0%

Table 38: Public Safety Facility HVAC System Utility Cost Comparison (2030)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling Utility ($/yr)	$12,128	$37,641	-$25,513	210.4%
Natural Gas Heating Utility ($/yr)	$22,857	$0	$22,857	-100.0%
TOTAL Heating/Cooling Utility ($/yr)	$34,985	$37,641	-$2,656	7.6%

Table 39: Public Safety Facility HVAC System GHG Emission Comparison (2030)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling (MTCO2e/yr)	14	42	-29	210.4%
Natural Gas Heating (MTCO2e/yr)	105	0	105	-100.0%
TOTAL Heating/Cooling (MTCO2e/yr)	118	42	76	-64.1%

Converting the PSF to a fully electrified building (2030) decreases overall energy use by 69.0%, while increasing electricity use by 210.4%. GHG emissions are reduced by 64.1%. The annual utility cost will increase by 7.6%.

Estimated Building Conversion Costs – Town of Acton

For compatibility with the LTHW distribution system for heating, all Town buildings will require a heating system conversion, including the removal of mechanical equipment served by HTHW, and replacement with equipment sized to meet the building heating loads at the LTHW design temperature. Building conversion work includes the replacement of both central equipment, such as AHUs and RTUs, and terminal equipment, such as finned tube radiators, reheat coils and FCUs.

Building conversion costs for each building were determined on a $/SF basis based on the age of the building, age of the HVAC system, HVAC system type, building use, and historic status. All of the town buildings were determined to be high-cost for building conversion to LTHW due to a combination of these factors. Table 40 shows the estimated building conversion costs for each town building. A full breakdown of estimated building conversion costs for each building can be found in Appendix C.

Table 40: Town of Acton Estimated Building Conversion Costs

Building Name	$/SF	Area (SF)	Conversion Cost ($)
Acton Town Hall	$35.00	24,144	$845,040
Acton Memorial Library	$35.00	48,259	$1,689,065
Public Safety Facility	$35.00	26,033	$911,155
Total		98,436	$3,445,260

Estimated Central Energy Plant Costs

Central energy plant costs cover the equipment and installation costs for the proposed energy plant in each building. This includes all new centralized equipment including ASHPs, boilers, hydronic pumps, and piping from new equipment to the mechanical room along with any associated accessories, controls, and electrical work. Table 41 shows the estimated energy plant costs for each town building. A full breakdown of estimated energy plant costs can be found in Appendix D.

Table 41: Town of Acton Estimated Energy Plant Costs

Building	Estimated Energy Plant Cost
Acton Town Hall	$1,107,000
Acton Memorial Library	$1,527,000
Public Safety Facility	$1,443,000
Total	$4,077,000

Estimated Maintenance Costs

Maintenance costs were estimated based on the size and type of each new system installed, along with a miscellaneous cost representing a portion of the BAU maintenance that will not change between the BAU and electrified options, which includes electrical, plumbing, building envelope and controls maintenance. Table 42 and Table 43 show the estimated annual maintenance costs for different types of HVAC systems and the estimated annual maintenance costs for each town building, respectively. These annual maintenance cost estimates have been developed over previous campus energy master planning projects, with input from manufacturers, facilities and operation staff. A full breakdown of estimated maintenance costs can be found in Appendix B. These estimated maintenance costs included in Table 42 have been applied to both Acton and ABRSD buildings.

Table 42: Estimated Annual Maintenance Costs of HVAC Systems

System Type	Estimated Annual Maintenance Cost
ASHP	$50/Ton
Air-Cooled Chiller	$50/Ton
RTU	$25/Ton
FCU	$25/Ton
Electric Boiler	$2,500 each

Table 43: Town of Acton Estimated Annual Maintenance Costs

Building	Estimated Annual Maintenance Cost
Acton Town Hall	$10,175
Acton Memorial Library	$17,645
Public Safety Facility	$18,580
Total	$46,400

Recommended Electrification Options – ABRSD

The electrification implementation timeline for the ABRSD buildings is included below in Figure 20. This implementation timeline includes all four building conversions to electrified HVAC systems by 2050 in alignment with the phased electrification goals of this study. The electrification conversion phasing by year is informed by the remaining service life of existing gas-fired equipment, with the goal of converting to electrical systems at or near the end of the gas-fired equipment's service life. The ABRSD has a comprehensive facility maintenance program and generally keeps their HVAC equipment in good working order. Through proactive preventative maintenance, the ABRSD is able to extend equipment's service life beyond ASHRAE guidelines. The implementation timeline for electrification of the ABRSD buildings includes extending the ASHRAE recommended service life for HVAC equipment by five years.

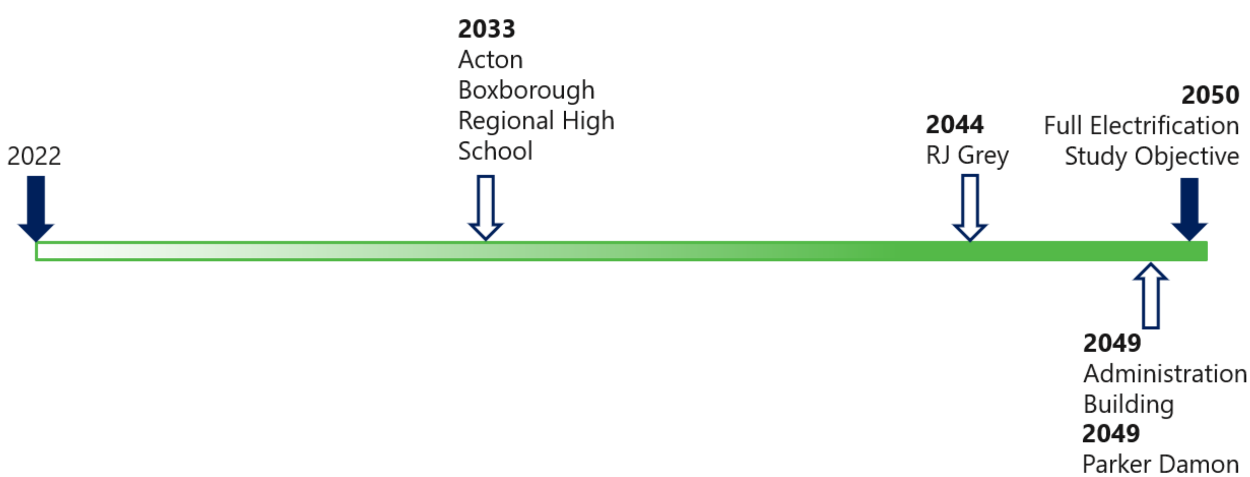


Figure 20: Acton-Boxborough Regional School District Implementation Plan

ABRHS

Overview

To achieve carbon neutrality by 2050 in alignment with state goals, ABRHS will be converted to all-electric systems in the year 2033, which coincides with the recommended replacement period of the existing natural gas boiler plant, maximizing the useful life of the existing boilers. As part of the electrification of the building's heating and cooling systems, a new energy plant will be installed which will consist of a 420 Ton ASHP system, 190 Ton air-cooled chiller system, 2,200 MBH electric boiler system and a solar thermal pool heating system with 1,500 SF of roof mounted panel collectors and 240 gallons of hot water storage. The solar thermal pool heating system will replace the existing electric heater and natural gas boiler pool heating system. The new ASHP system will consist of four 105 ton units which will be installed either on grade or on the roof in a new equipment enclosure. The new ASHP system is designed to handle the majority of the annual heating and cooling load while the electric boiler system is sized for peak heating and air-cooled chiller system is sized for peak cooling. A cost-benefit analysis was conducted to size the peak heating and cooling systems which led to utilizing both an electric boiler for peak heating and air-cooled chiller for peak cooling. As these peak heating/cooling systems had very little annual run-hours, the energy savings associated with upsizing ASHPs to cover peak loads were significantly outweighed by the additional capital cost of the ASHPs. Figure 21 below shows the ABRHS monthly average load profile over the course of a year.

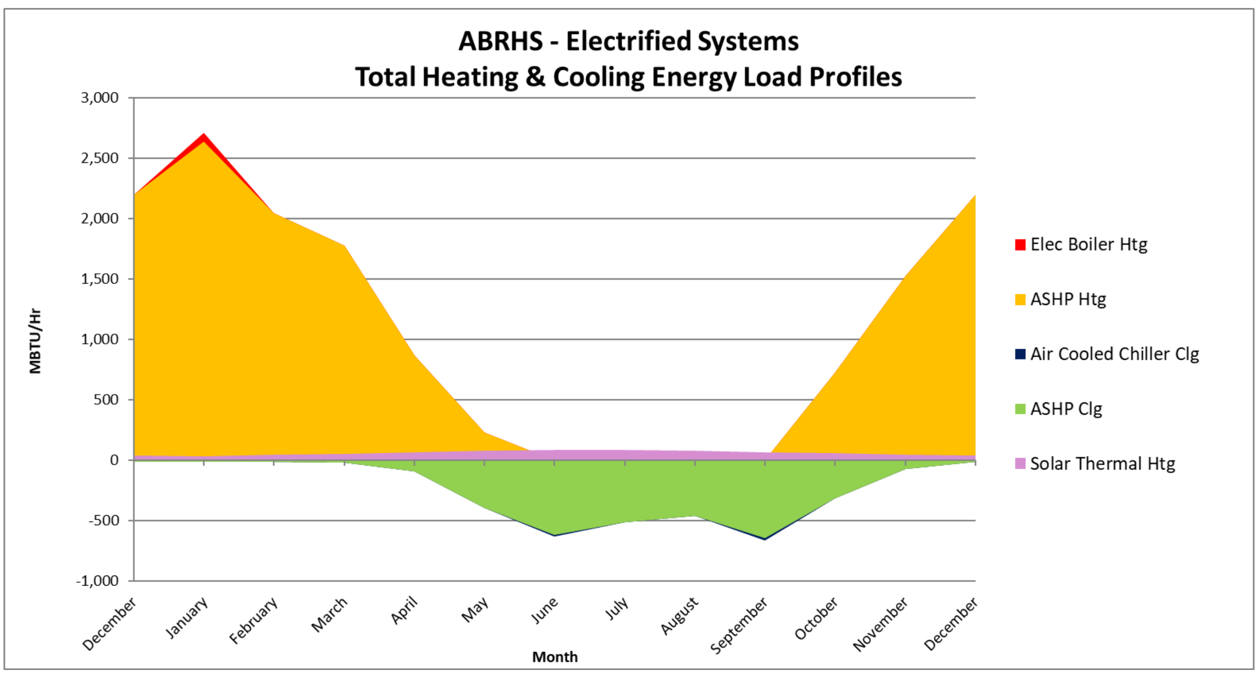


Figure 21: ABRHS Annual Heating & Cooling Load Profile

ABRSD is currently working with GGD Engineering on a Renewable Thermal Technical Study regarding the replacement of the 11 Jackson Church RTUs with new all-electric RTUs instead of the hydronic (HW/CHW) RTUs carried in this report.

Electrical Infrastructure

The proposed work includes removal of the existing RTUs and the installation of one 650 kW electric boiler, four ASHPs, two 15 HP pumps, two 3 HP pumps (run/standby), (24) HW/CHW RTU's and one 190-ton chiller.

Disconnect and remove existing RTUs and associated circuitry completely. Maintain breakers as spares. New RTU's to be fed from existing panels/switchboards. Contractor may utilize existing breakers from removal of existing RTU's where feasible.

Provide a new 1500 kVA, 13.8 kV to 480V pad-mounted service transformer. Provide a new 2000 A, 3-phase, 4-wire switchboard for new mechanical loads. Provide with one 1000 A, 3-phase breaker for "MEDP", one 250 A, 3-phase breakers for new ASHPs, one 500 A, 3-phase breaker for new chiller and one 1000 A, 3-phase breaker for new electric boiler.

Provide two 35A, 3-phase breakers for RTU's 22 and 23, two 30A, 3-phase breakers for RTU's 20 and 21, as well as twenty 20A, 3-phase breakers for RTU's 1 to 19 and RTU-24.

The existing 250 kW generator and associated 600 A switchgear "MEDP" is inadequately sized for the proposed mechanical loads. Disconnect and remove existing 250 kW generator and associated transfer switch completely and replace with a new 700 kW generator and 1000 A transfer switch. Disconnect and remove existing emergency switchboard "MEDP" completely. Maintain existing circuitry as required for reconnection to new switchboard. Provide a new 1000 A, 480/277 V, 3-phase, 4-wire switchboard "MEDP". Provide with matching breakers for existing loads. Reconnect by necessary means existing circuitry. Provide four 250 A, 3-phase breakers for new ASHPs and two 30 A, 3-phase breakers for additional pumps and two 20 A, 3-phase breakers for additional pumps. Provide complete circuitry to new mechanical equipment.

Performance: Energy, Carbon, Utility Cost

The effects of electrifying the building's heating and cooling system on the annual energy consumption, utility costs and GHG emissions are outlined in Table 44,

Table 45 and Table 46 below.

Table 44: ABRHS HVAC System Energy Consumption Comparison (2050)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling (KWH/yr)	328,485	1,364,461	-1,035,977	315%
Natural Gas Heating (Therm/yr)	110,923	0	110,923	-100%
TOTAL Heating/Cooling Energy (MBTU/yr)	12,213,090	4,655,542	7,557,548	-62%

Table 45: ABRHS HVAC System Utility Cost Comparison (2050)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling Utility ($/yr)	$56,171	$233,323	-$177,152	315%
Natural Gas Heating Utility ($/yr)	$123,125	$0	$123,125	-100%
TOTAL Heating/Cooling Utility ($/yr)	$179,295	$233,323	-$54,027	30%

Table 46: ABRHS HVAC System GHG Emission Comparison (2050)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling (MTCO2e/yr)	0	0	0	0%
Natural Gas Heating (MTCO2e/yr)	589	0	589	-100%
TOTAL Heating/Cooling (MTCO2e/yr)	589	0	589	-100%

Electrifying the ABRHS heating and cooling systems (2050) reduces overall energy use by 62%, while increasing electricity use by 315%. GHG emissions are reduced by 100%. The annual utility cost will increase 30%.

RJ Grey

Overview

To achieve carbon neutrality by 2050 in alignment with state goals, RJ Grey will be converted to all-electric systems in the year 2044. Of the major existing HVAC components serving the building, the natural gas boiler is expected to reach the end of its service life first, in 2044. To maximize the usefulness of the existing equipment, it was recommended that RJ Grey be converted to the electrified system in 2044.

The new electrified RJ Grey energy plant will consist of a 140 Ton ASHP system and a 1,250 MBH electric boiler system. The new ASHP system will consist of two 70 Ton ASHPs which will be installed either on grade or on the roof in a new equipment enclosure. The new ASHP system is designed to handle the peak building cooling load of 140 Tons and will also handle most of the annual heating load. The peak heating load will be met by the electric boiler system. Figure 22 below shows the RJ Grey monthly average load profile over the course of a year.

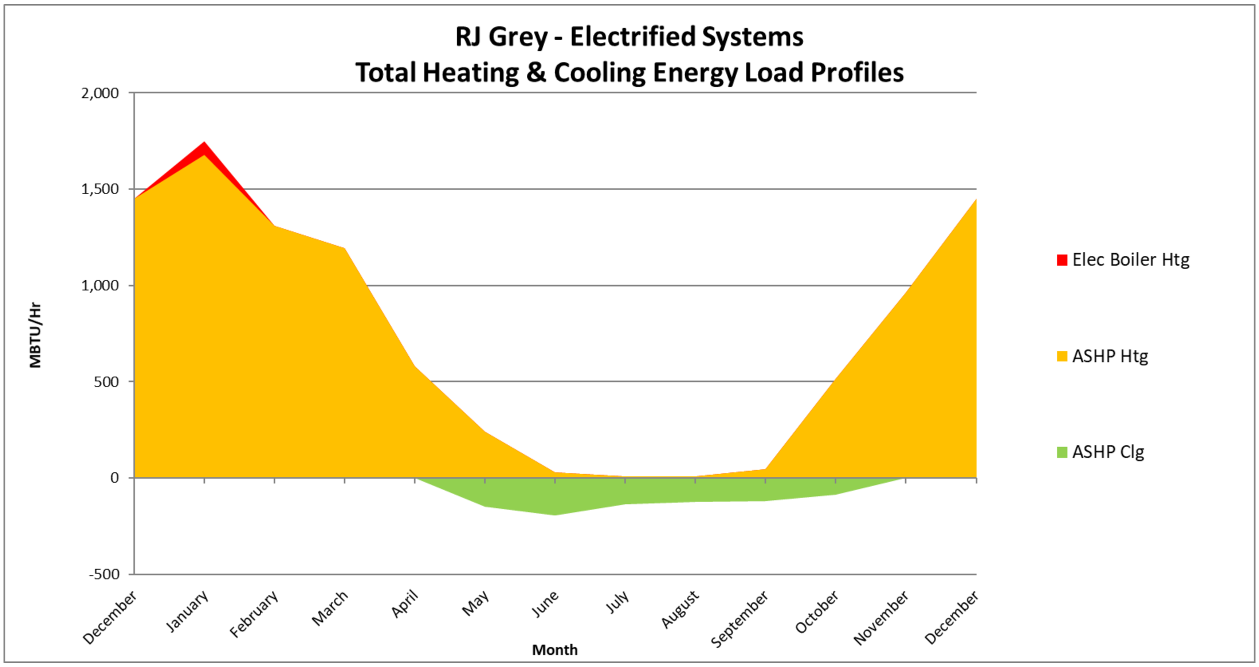


Figure 22: RJ Grey Annual Heating & Cooling Load Profile

Electrical Infrastructure

The proposed work includes removal of the existing RTUs and the installation of two 92 kW ASHPs, two 10 HP CHW pumps (run/standby) and one 366 kW electric boiler.

Disconnect and remove existing RTUs and associated circuitry completely. Maintain breakers as spares. New RTU's to be fed from existing panels/switchboards. Contractor may utilize existing breakers from removal of existing RTU's where feasible.

Provide a 1000 A, 3-phase breaker in existing switchboard to feed a new 1000 A, 3-phase, 4-wire distribution board "MDP". Provide one 450 A, 3-phase breaker in "MDP" for power to boiler. Two new 150 A, 3-phase breakers for the ASHPs, and one new 300 A, 3-phase breaker for new "ATS".

Provide (14) 30A, 3-phase breakers for RTU's 1 to 14.

Provide a new 175 kW, 480/277 V, 3-phase, 4-wire generator with a 400 A, 3-phase, 4-wire transfer switch. Provide a new 400 A, 3-phase, 4-wire Panel "EHP" with a 400 A main breaker for power to ASHPs and 10 HP pumps. Provide with two 150 A, 3-phase breakers for ASHPs and two 20 A, 3-phase breakers for pumps.

Performance: Energy, Carbon, Utility Cost

The effects of electrifying the building's heating and cooling system on the annual energy consumption, utility costs and GHG emissions are outlined in Table 47, Table 48 and Table 49 below.

Table 47: RJ Grey HVAC System Energy Consumption Comparison (2050)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling (KWH/yr)	89,223	860,450	-771,226	864%
Natural Gas Heating (Therm/yr)	73,315	0	73,314	-100%
TOTAL Heating/Cooling Energy (MBTU/yr)	7,635,888	2,935,855	4,700,032	-62%

Table 48: RJ Grey HVAC System Utility Cost Comparison (2050)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling Utility ($/yr)	$15,257	$147,137	-$131,879	864%
Natural Gas Heating Utility ($/yr)	$81,379	$0	$81,379	-100%
TOTAL Heating/Cooling Utility ($/yr)	$96,636	$147,137	-$50,500	52%

Table 49: RJ Grey HVAC System GHG Emission Comparison (2050)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling (MTCO2e/yr)	0	0	0	0%
Natural Gas Heating (MTCO2e/yr)	389	0	389	-100%
TOTAL Heating/Cooling (MTCO2e/yr)	389	0	389	-100%

Electrifying the RJ Grey heating and cooling systems (2050) reduces overall energy use by 62%, while increasing electricity use by 864%. GHG emissions are reduced by 100%. The annual utility cost will increase 52%.

Parker Damon Building

Overview

To achieve carbon neutrality by 2050 in alignment with state goals, Parker Damon will be converted to all-electric systems in the year 2049. Of the major existing HVAC components serving the building, the natural gas boiler is expected to reach the end of its service life first, in 2049. To maximize the usefulness of the existing equipment, it was recommended that Parker Damon be converted to the electrified system in 2049.

The new electrified Parker Damon energy plant will consist of a 150 Ton ASHP system and a 1,000 MBH electric boiler system. The new ASHP system will consist of two 75 Ton ASHPs which will be installed either on the roof or on grade in a new equipment enclosure. The existing 224 Ton air-cooled chiller will be replaced in kind. The ASHPs will be base loaded to handle the majority of the annual heating and cooling energy but will not meet the peak cooling and heating loads; these seasonal peaks will be met by the air-cooled chiller and electric boiler. Figure 23 below shows the Parker Damon monthly average load profile over the course of a year.

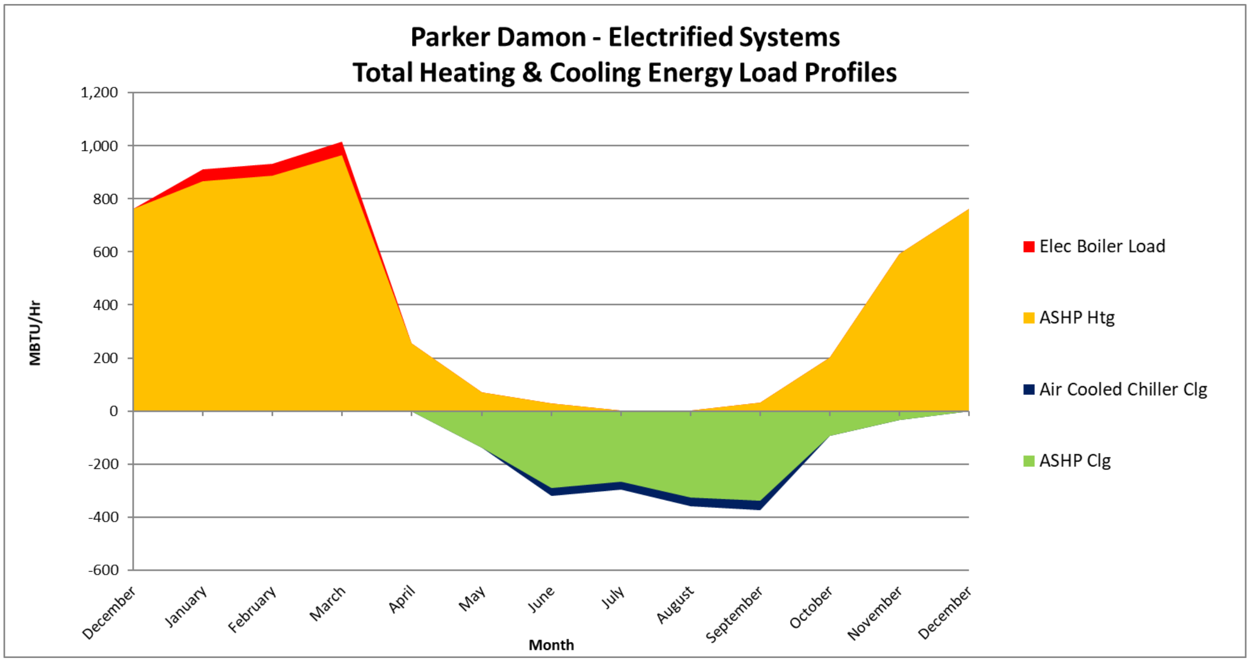


Figure 23: Parker Damon Annual Heating & Cooling Load Profile

Electrical Infrastructure

The proposed work includes removal of the existing RTUs and the installation of two 106.5 kW ASHPs, two 3 HP CHW pumps (run/standby), two 10 HP CHW pumps and one 300 kW electric boiler.

Disconnect and remove existing RTUs and associated circuitry completely. Maintain breakers as spares. New RTU's to be fed from existing panels/switchboards. Contractor may utilize existing breakers from removal of existing RTU's where feasible.

Provide a new 400 A, 3-phase breaker in existing "MSB" to feed new electric boiler, two 150 A, 3-phase breakers for ASHPs and one 400 A, 3-phase breaker for new automatic transfer switch.

Provide seven 30A, 3-phase breakers for RTU's 1 to 7.

Existing 100 kW generator and associated transfer switch are inadequate and shall be disconnected and removed completely and replaced with a new 200 kW generator with 400 A transfer switch. A new 400 A, 3-phase, 4-wire panelboard "EHP-1" shall be installed for emergency loads. Provide with two 150 A, 3-phase breaker for ASHPs, two 20 A, 3-phase breakers for CHW pumps, two 20 A, 3-phase breaker for additional pumps and one 50 A, 3-phase breaker for existing transformer.

Provide complete circuitry to new mechanical equipment.

Performance: Energy, Carbon, Utility Cost

The effects of electrifying the building's heating and cooling system on the annual energy consumption, utility costs and GHG emissions are outlined in Table 50, Table 51 and Table 52 below.

Table 50: Parker Damon Building HVAC System Energy Consumption Comparison (2050)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling (KWH/yr)	150,017	581,143	-431,126	287%
Natural Gas Heating (Therm/yr)	43,340	0	43,340	-100%
TOTAL Heating/Cooling Energy (MBTU/yr)	4,845,888	1,982,859	2,863,028	-59%

Table 51: Parker Damon HVAC System Utility Cost Comparison (2050)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling Utility ($/yr)	$25,653	$99,375	-$73,723	287%
Natural Gas Heating Utility ($/yr)	$48,108	$0	$48,108	-100%
TOTAL Heating/Cooling Utility ($/yr)	$73,761	$99,375	-$25,615	35%

Table 52: Parker Damon HVAC System GHG Emission Comparison (2050)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling (MTCO2e/yr)	0	0	0	0%
Natural Gas Heating (MTCO2e/yr)	230	0	230	-100%
TOTAL Heating/Cooling (MTCO2e/yr)	230	0	230	-100%

Electrifying the Parker Damon heating and cooling systems (2050) reduces overall energy use by 59%, while increasing electricity use by 287%. GHG emissions are reduced by 100%. The annual utility cost will increase by 35%.

Administration Building

Overview

To achieve carbon neutrality by 2050 in alignment with state goals, the Administration Building will be converted to all-electric systems in the year 2049. Of the major existing HVAC components serving the building, the older of the two natural gas boilers is expected to reach the end of its useful life first, in 2049. To maximize the usefulness of the existing equipment, it was recommended that the Administration Building be converted to the electrified system in 2049.

The new electrified Administration Building energy plant will consist of a 150 Ton ASHP system. The new ASHP system will consist of two 75 ton ASHPs which will be installed either on the roof or on grade in a new equipment enclosure. The new ASHP system will be sized to satisfy the building's peak heating load and peak cooling load. To avoid losing all heating or cooling due to an equipment failure, these two ASHPs are each sized at 75% of the buildings peak heating load. This peak cooling load accounts for the additional load anticipated to fully cool the building. Figure 24 below shows the Administration Building monthly average load profile over the course of a year.

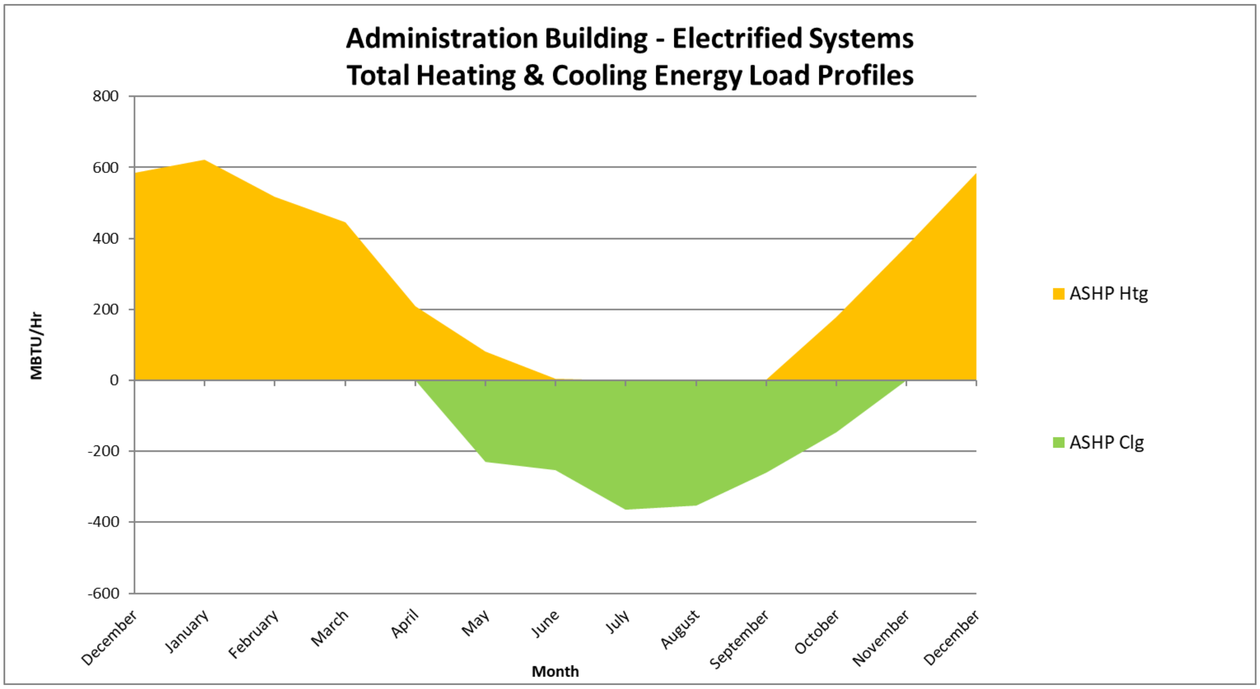


Figure 24: Administration Building Annual Heating & Cooling Load Profile

Electrical Infrastructure

The proposed work includes the installation of two 79 kW ASHPs, two 3 HP CHW pumps (run/standby) and one 200 kW electric boiler.

Provide two 175 A, 3-phase breakers in existing switchboard for power to ASHPs and one 400 A, 3-phase breaker for new ATS.

Provide a 125 kW, 208/120 V, 3-phase, 4-wire generator with a 400 A, 3-phase, 4-wire transfer switch. Provide a 400 A, 3-phase, 4-wire Panel with a 400 A main breaker for power to new ASHPs and 10 HP pumps. Provide with two 175 A, 3-phase breakers for ASHPs and two 30 A, 3-phase breakers for pumps.

Provide complete circuitry to new mechanical equipment.

Performance: Energy, Carbon, Utility Cost

The effects of electrifying the building's heating and cooling system on the annual energy consumption, utility costs and GHG emissions are outlined in Table 53, Table 54 and Table 55 below.

Table 53: Administration Building HVAC System Energy Consumption Comparison (2050)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling (KWH/yr)	150,229	401,817	-251,588	167%
Natural Gas Heating (Therm/yr)	24,992	0	24,992	-100%
TOTAL Heating/Cooling Energy (MBTU/yr)	3,011,813	1,370,999	1,640,814	-54%

Table 54: Administration Building HVAC System Utility Cost Comparison (2050)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling Utility ($/yr)	$25,689	$68,711	-$43,022	167%
Natural Gas Heating Utility ($/yr)	$27,741	$0	$27,742	-100%
TOTAL Heating/Cooling Utility ($/yr)	$53,431	$68,711	-$15,280	29%

Table 55: Administration Building HVAC System GHG Emission Comparison (2050)

	BAU System	Electrified System	Savings	% Change
Electric Heating/Cooling (MTCO2e/yr)	0	0	0	0%
Natural Gas Heating (MTCO2e/yr)	133	0	133	-100%
TOTAL Heating/Cooling (MTCO2e/yr)	133	0	133	-100%

Electrifying the Administration Building heating plus additional cooling systems (2050) reduces overall energy use by 54%, while increasing electricity use by 167%. GHG emissions are reduced by 100%. The annual utility cost increases by 29%.

Estimated Building Conversion Costs - ABRSD

For compatibility with the LTHW distribution system for heating, all ABRSD buildings will require a heating system conversion, including the removal of mechanical equipment served by HTHW, and replacement with equipment sized to meet the building heating loads at the LTHW design temperature. Building conversion work includes the replacement of both central equipment, such as AHUs and RTUs, and terminal equipment, such as finned tube radiators, reheat coils and FCUs.

Building conversion costs for each building were determined on a $/SF basis based on the age of the building, age of the HVAC system, HVAC system type, building use, and historic status. All of the ABRSD buildings were determined to be high-cost for building conversion to LTHW due to a combination of these factors. Table 56 shows the estimated building conversion costs for each ABRSD building. A full breakdown of estimated building conversion costs for each building can be found in Appendix C.

Table 56: ABRSD Estimated Building Conversion Costs

Building	$/SF	Area (SF)	Conversion Cost ($)
ABRHS	$35.00	386,000	$13,510,000
RJ Grey Junior High	$35.00	143,000	$5,005,000
Parker Damon	$35.00	142,000	$4,970,000
Administration Building	$35.00	36,000	$1,260,000
Total		707,000	$24,745,000

Estimated Central Energy Plant Costs

Central energy plant costs cover the equipment and installation costs for the proposed energy plant in each building. This includes all new centralized equipment including ASHPs, boilers, solar thermal equipment, air-cooled chillers, hydronic pumps, and piping from any new equipment to the mechanical room along with any associated accessories, controls, and electrical work. Table 57 shows the estimated energy plant costs for each ABRSD building. A full breakdown of estimated energy plant costs can be found in Appendix D.

Table 57: ABRSD Estimated Energy Plant Costs

Building	Estimated Energy Plant Cost
ABRHS	$4,700,000
RJ Grey Junior High	$1,728,000
Parker Damon	$2,366,000
Administration Building	$1,604,000
Total	$10,398,000

Estimated Maintenance Costs

Maintenance costs were estimated based on the size and type of each new system installed. Table 58 and Table 59 show the estimated annual maintenance costs for different types of HVAC systems and the estimated annual maintenance costs for each ABRSD building, respectively. A full breakdown of estimated maintenance costs can be found in Appendix B. These estimated maintenance costs included in Table 58 have been applied to both Acton and ABRSD buildings.

Table 58: Estimated Annual Maintenance Costs of HVAC Systems

System Type	Estimated Annual Maintenance Cost
ASHP	$50/Ton
Air-Cooled Chiller	$50/Ton
RTU	$25/Ton
FCU	$25/Ton
Electric Boiler	$2,500 each
Solar Thermal	$250 per 1,500 SF collector

Table 59: ABRSD Estimated Annual Maintenance Costs

Building	Estimated Annual Maintenance Cost
ABRHS	$48,500
Administration Building	$11,250
Parker Damon	$30,550
RJ Grey Junior High	$13,000
Total	$103,300

Rebates and Incentives

There are potential rebates and incentives available through state agencies and utility companies for projects that reduce energy use and reduce GHG emissions. For example, Mass Save, through utility company sponsors, currently has a heat pump rebate program offering a dollars per Ton rebate for the installation of electrified HVAC systems, including GSHPs, ASHPs and Variable Refrigerant Flow (VRF) systems[ii]. The current rebate amounts are included below in Table 60 and max out at 50 Tons; however, Nation Grid indicated that a potential expansion of the rebate program to system capacities up to 100 Tons was under consideration.

Table 60: Current National Grid Heat Pump Rebate Amounts

System Type	Rebate Amount ($/Ton)
GSHP	$4,500
VRF	$3,500
ASHP	$2,500

In addition to traditional, prescriptive utility rebates, and in light of the complex, custom nature and long implementation schedule outlined here, there may be an opportunity for a custom rebate geared towards specific components of this study. Additional coordination with state agencies and utility companies during design and implementation will be required to identify custom rebates or other incentive opportunities.

Advanced Energy Credits (AECs) are a state financial incentive for buildings adopting "clean heat" technology such as electrification. The MA Alternative Energy Performance Standard (APS) provides for minting AEC certificates quarterly as incentive payments for buildings heating with efficient electric technology[iii]. This revenue stream will help to partially offset energy costs associated with building operation.

AECs are calculated in accordance with the Massachusetts Guideline on Metering and Calculating the Useful Thermal Output of Eligible Renewable Thermal Generation Units. Calculated annual AECs for the proposed ASHP systems for each building are found in Table 61 below. Refer to Appendix F for additional information on AEC calculations. It is important to note that the Public Safety Facility, Acton Town Hall and Administration Building have multipliers of 3 because the ASHPs included in in the proposed electrified option are designed to provide 100% of each building's heating energy.

Table 61: Estimated Annual AECs for All Buildings

Building	Net Thermal Energy Output Equivalent (MWh)	Renewable Thermal Generation Unit Multiplier	AECs
Acton Memorial Library	25	1	25
Public Safety Facility	20	3	60
Acton Town Hall	11	3	33
ABRHS	32	1	32
RJ Grey Junior High	6	1	6
Parker Damon	13	1	13
Administration Building	24	3	72

Life Cycle Cost Analysis (LCCA) - Overview

Assumptions

The relative economic and environmental performance for both the Town of Acton buildings and the ABRSD buildings was evaluated using a Life-Cycle Cost Analysis (LCCA) model. The LCCA model used the discount and escalation rates included in Table 62. The forecast period is 30 years with the first forecast year being 2022 and the final forecast year being 2051.

Table 62: LCCA Discount and Annual Escalation Rates

LCCA Rate Information	
Inflation Rate	2.48%
Real Discount Rate	4.50%
Natural Gas Escalation Rate	2.60%
Electric Escalation Rate	2.50%
Nominal Discount Rate	7.09%

The electrification options were compared to the BAU reference case using the Net Present Value of all future cash flow throughout the forecast period. The LCCA model discounts all future cash flows to 2022 dollars using a 4.5% real discount rate. The inflation rate of 2.48% represents the average yearly inflation rate provided by the US Bureau of Labor Statistics from 1990 through 2021. Escalation rates for natural gas and electricity were determined using the online Department of Energy's Energy Escalation Rate Calculator (EERC), with input from Massachusetts Department of Energy Resources (DOER). The EERC determines escalation rates for a specified period based on the Energy Information Administration (EIA) energy price projections by state.

Purchased Carbon Offsets

The LCCA does not include the cost of purchasing carbon offsets to negate any CO_2 emissions released by the building thermal energy systems. Carbon offsets can take the form of certificates which represents the reduction of one ton of carbon dioxide emissions. This reduction is achieved through the funding of projects which remove or avoid carbon emissions such as renewable energy projects and carbon capture projects.

Carbon Tax and Emissions Penalties

This LCCA does not include any costs associated with a potential carbon tax. As of the writing of this report, there is no Massachusetts or federal tax or fee imposed on carbon emissions. Applying a carbon tax, or social cost of carbon, can help understand the long-term environmental and financial risks associated with carbon emissions of infrastructure decisions. The EPA and other federal agencies use estimates of the social cost of carbon to value the climate impacts of rulemakings. The social cost of carbon is a measure, in dollars, of the long-term damage done by a metric ton of carbon dioxide ($MTCO_2$) emissions in a given year. This dollar figure also represents the value of damages avoided for a small emission reduction (i.e., the benefit of a CO_2 reduction)[iv]. A carbon tax could also be structured to cover other GHG emissions by calculating their global warming potential relative to carbon dioxide.

Outside of the United States, many countries have enacted a carbon tax. Within the United States, various states and regions, including Oregon, Washington, California and New England, have or are currently considering a carbon tax or Emissions Trading Systems (ETS). An ETS, or cap-and-trade system, would cap total emissions levels and allow those with low emissions to sell their excess emissions capacity to higher emitters. The trading systems would establish a market price for GHG emissions.

Emissions reporting is now required in several cities (e.g., New York City's Local Law 97, and Boston's Building Emissions Reduction and Disclosure (BERDO) ordinance), with potential fines for exceeding emissions limits. The policy risk of a carbon tax or other emissions penalty would drive up the cost of heating with fossil fuels, making low or zero-carbon investments more market competitive. The economic implications of taxing pollution are well understood, but it is difficult at this time to determine how to apply it in this analysis and if applied, what value to use.

Utility Costs

According to utility bills provided by both the Town of Acton and the ABRSD, the average price for natural gas was $1.11 per Therm. As per the EERC previously discussed, a 2.6% escalation per year was used for natural gas in the LCCA, resulting in a 2051 natural gas price approaching $2.40 per Therm. The assumed natural gas price forecast is shown in Figure 25 below.

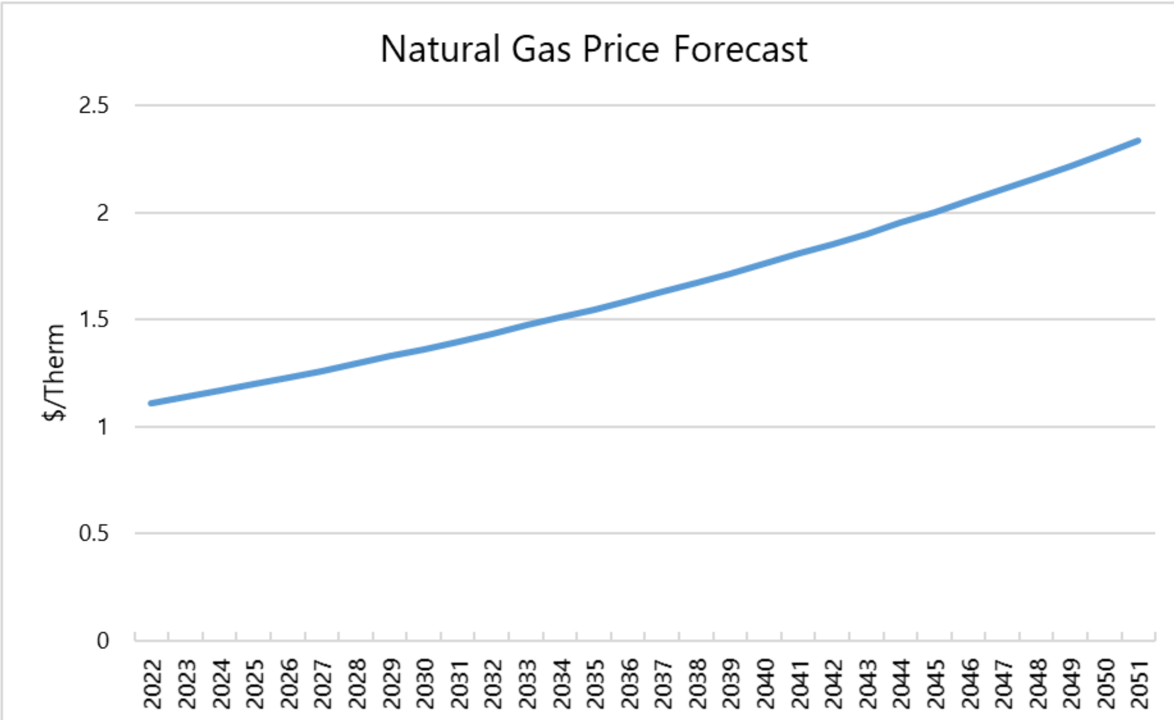


Figure 25: Natural Gas Price Forecast

According to the utility bills provided by both the Town of Acton and ABRSD, the average price for electricity was $0.17 per kWh. As per the EERC previously discussed, a 2.5% escalation per year was used for electricity in the LCCA, resulting in a 2051 purchased electricity price exceeding $0.36 per kWh. The assumed price forecast is shown in Figure 26 below.

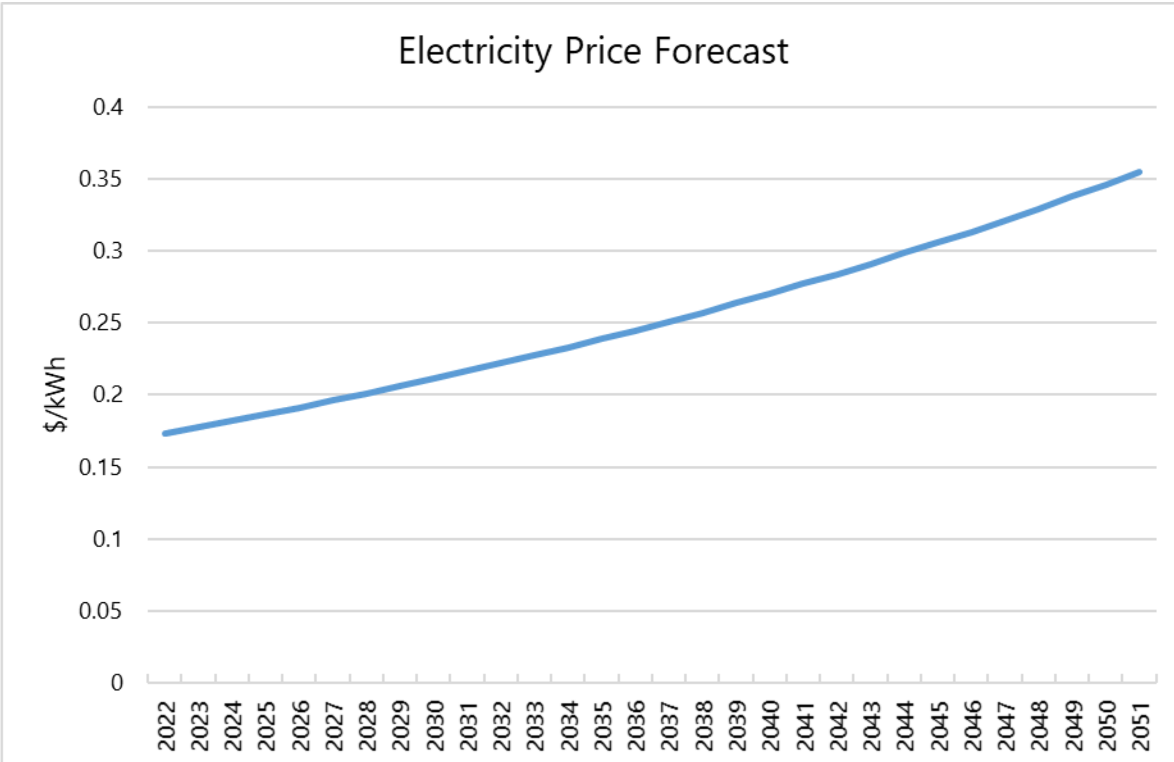


Figure 26: Electricity Price Forecast

Life Cycle Cost Analysis (LCCA) – Town of Acton

Capital Costs

Capital costs for the Town of Acton BAU case include replacement of HVAC systems that have reached the end of their service life during the study period in each building. For the electrified systems, capital costs include the costs of new energy plants and building conversions – this is seen in the 'Investment Costs' row in Table 63 below. Capital costs for the BAU scenario are summarized in Appendix A. The electrified option capital costs are summarized in Appendix C and Appendix D. Figure 27 below illustrates the comparative flow of capital costs (in 2022 dollars) throughout the forecast period.

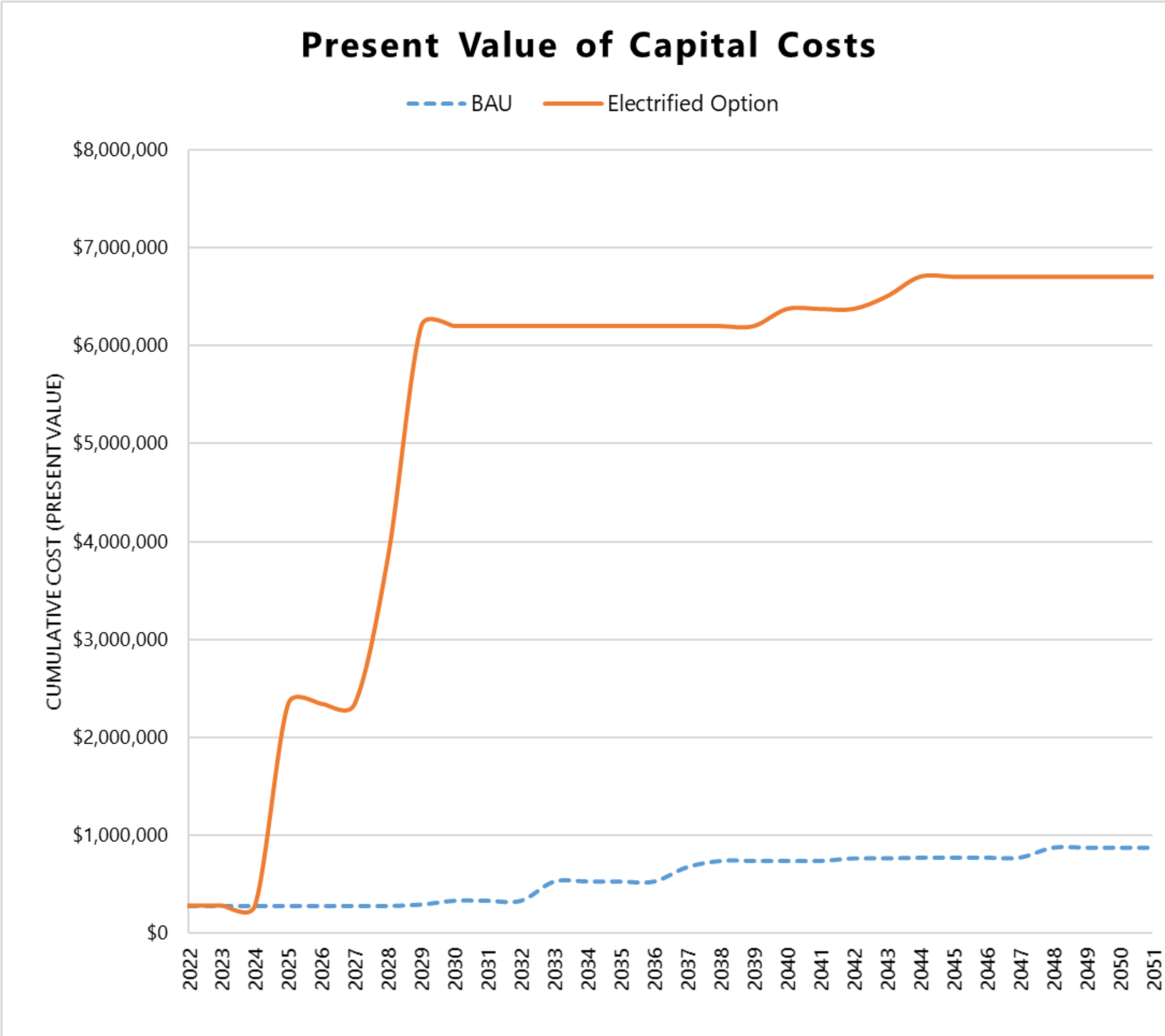


Figure 27: Town of Acton LCCA Capital Costs

Relative Economic Performance

A summary of costs and the present value comparison of the proposed electrified systems option to the BAU case is included below in Table 63 and Figure 28. Although the Electrified Option eliminates natural gas use by 2030, there is still a natural gas cost included in the LCCA from natural gas use between 2022-2030 before all buildings have been electrified. Additional details on the LCCA are included in Appendix E.

Table 63: Town of Acton – LCCA Results

30 Year Life Cycle - Economic Comparison			
Option:	**BAU**	**Electrification Option**	**Delta**
Elec Utility Cost	$633,386	$1,476,561	$843,175
NG Utility Cost	$1,115,582	$365,092	-$750,490
Total Utility Costs	$1,748,969	$1,841,654	$92,685
Maintenance Costs	$1,368,560	$931,087	-$437,473
Investment Costs	$867,242	$6,709,989	$5,842,746
30 Year Life Cycle Cost	$3,984,771	$9,482,729	$5,497,958

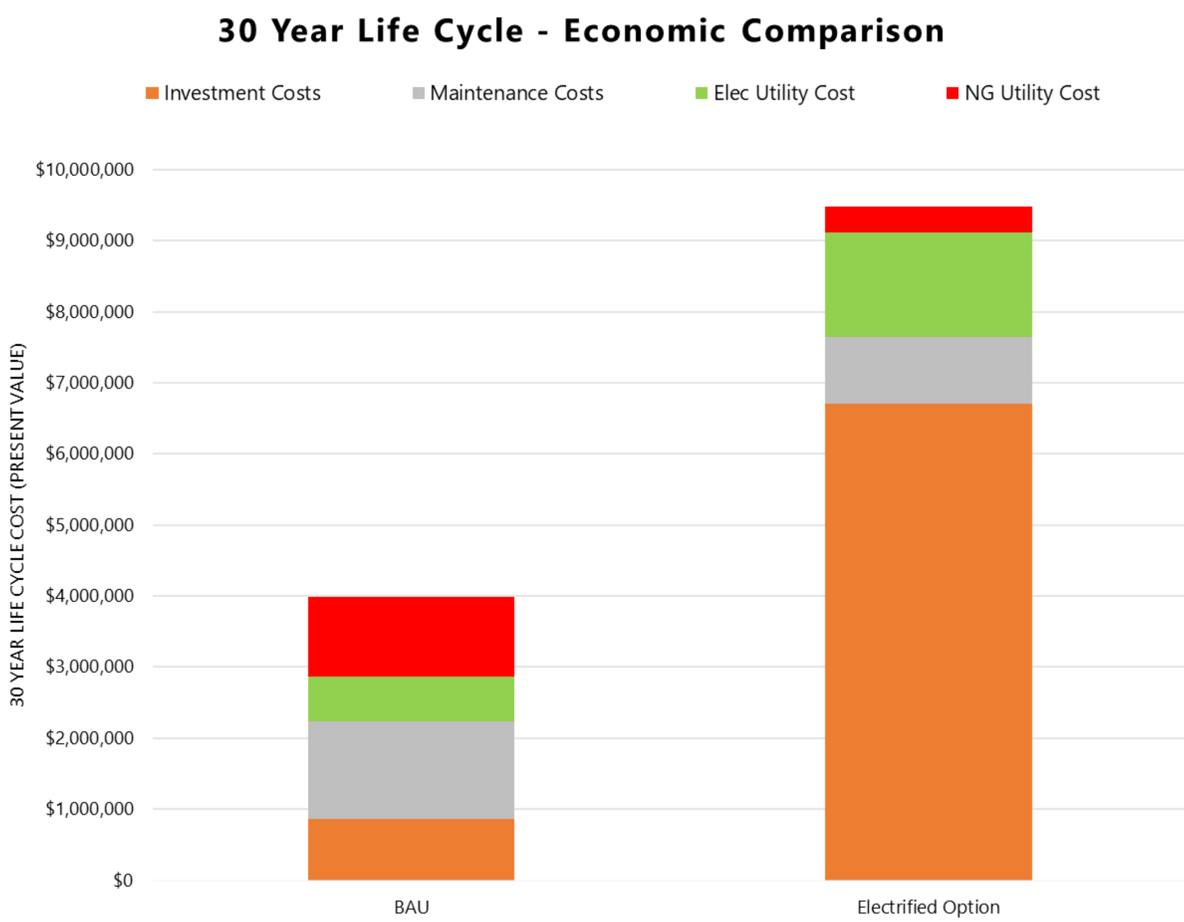


Figure 28: Town of Acton LCCA Present Value Comparison

The present value of cash flow for the BAU case and the proposed electrified systems option is shown in Figure 29 below. Compared to the BAU case, there is no break even point during the 30-year LCCA. Over the 30-year LCCA, the proposed electrified systems option costs $5.5M over the BAU case. Operating costs, including maintenance and energy, drop with building electrification. The major driver of the increased cost between the Electrified Option and the BAU case is the capital cost which could be reduced by support from state and federal grants.

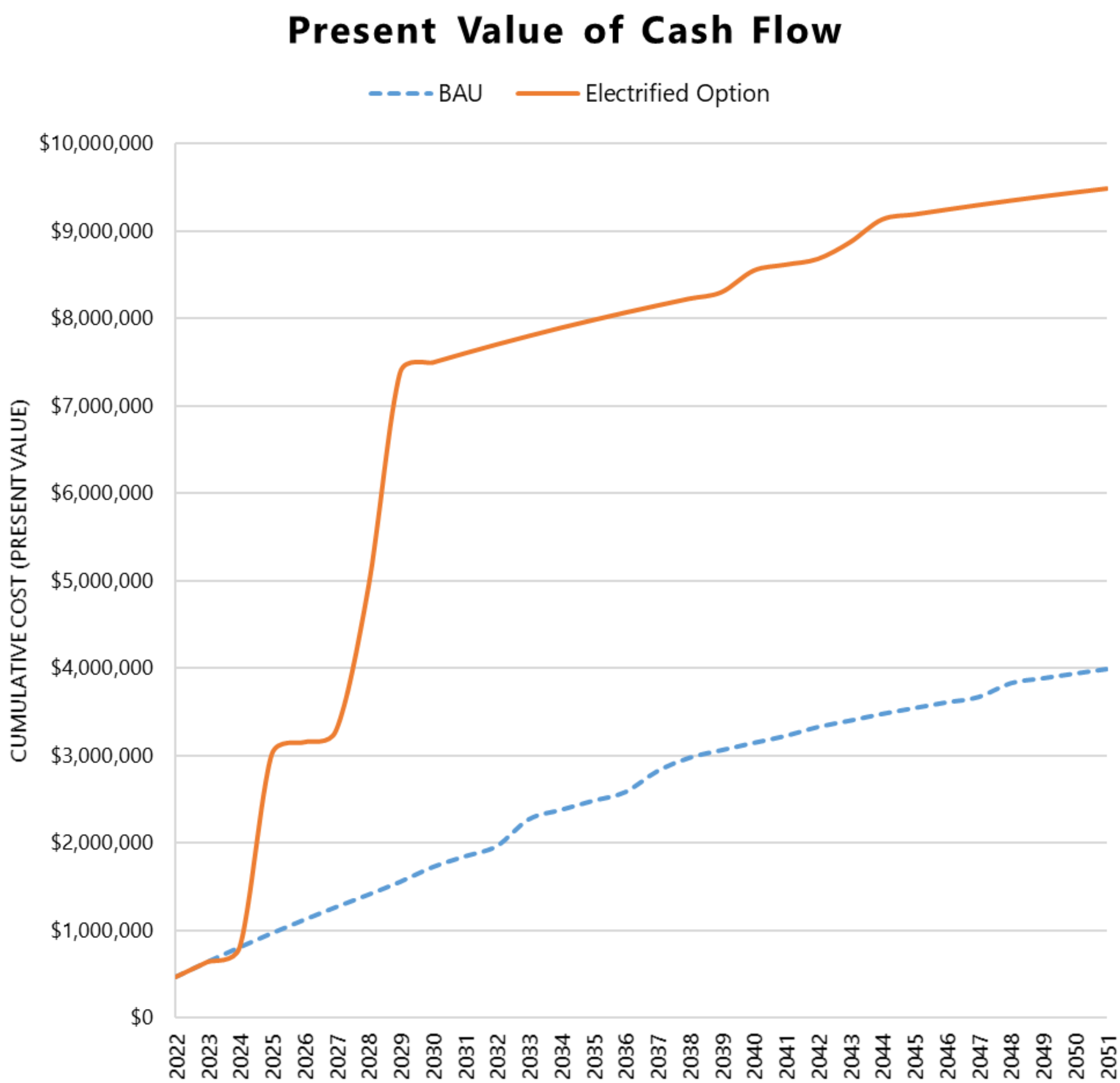


Figure 29: Town of Acton LCCA Present Value Cash Flow

For the Town of Acton, the projected operating costs, including maintenance and utility costs, are reduced with building electrification. The projected annual operating costs for the completed electrified option (2051) are seen in 2022 dollars in Table 64 and reflect an annual cost savings of $24,842.

Table 64: Town of Acton – Operational Costs Comparison

2051 Annual Operating Costs - Economic Comparison			
	BAU	**Electrification Option**	**Delta**
Elec Utility Cost	$37,137	$110,985	$73,848
NG Utility Cost	$64,690	$0	-$64,690
Maintenance Costs	$80,400	$46,400	-$34,000
Total Operational Costs	$182,227	$157,385	-$24,842

Life Cycle Cost Analysis (LCCA) – ABRSD

Capital Costs

Capital costs for the ABRSD BAU case include replacement of HVAC systems that have reached the end of their service life during the study period in each building. For the electrified systems, capital costs include the costs of new energy plants and building conversions – this is seen in the 'Investment Costs' row in Table 65 below. Capital costs for the BAU scenario are summarized in Appendix A. The electrified option capital costs are summarized in Appendix C and Appendix D. Figure 30 below illustrates the comparative flow of capital costs (in 2022 dollars) throughout the forecast period.

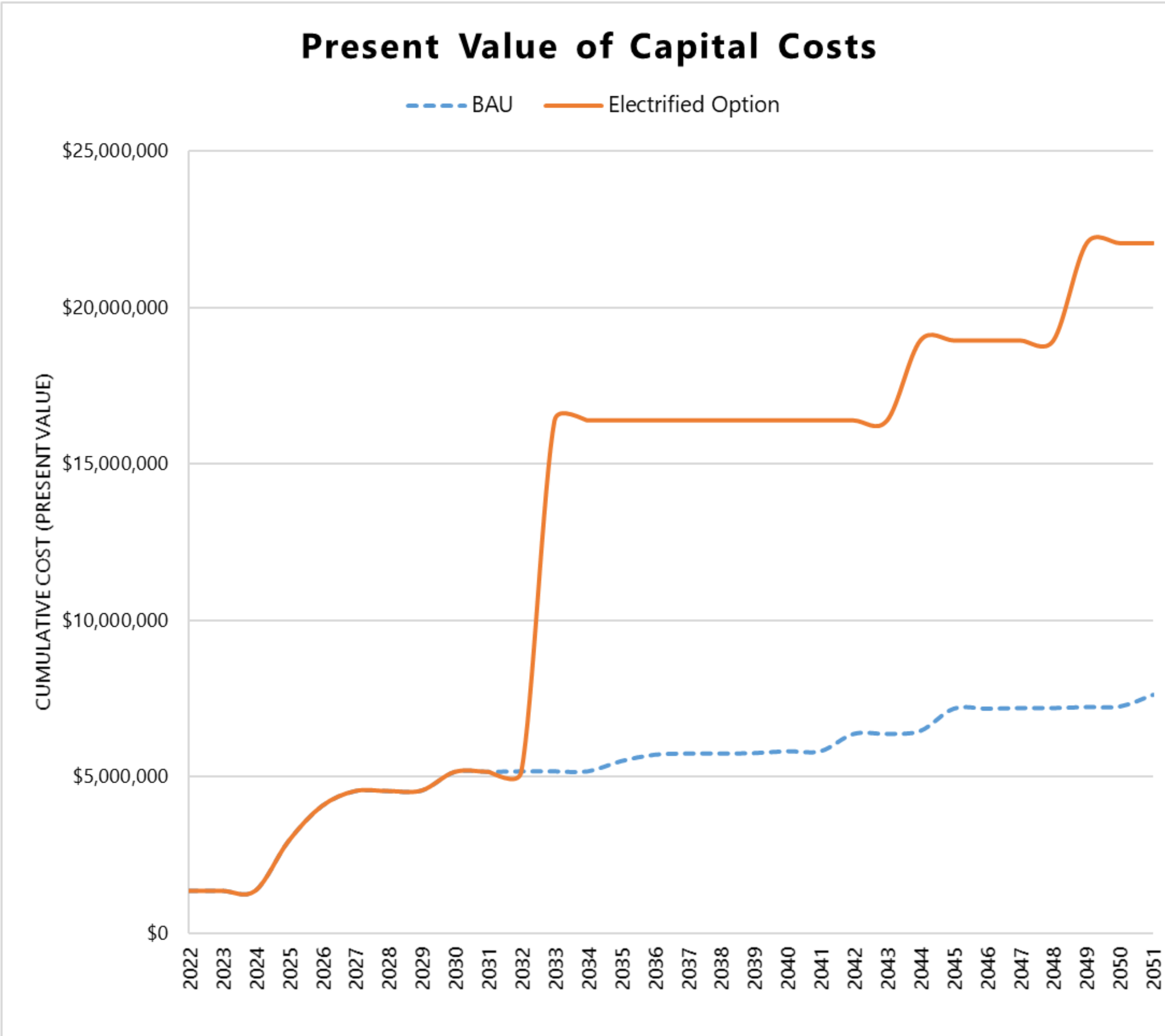


Figure 30: ABRSD LCCA Capital Costs

Relative Economic Performance

A summary of costs and the present value comparison of the proposed electrified systems option to the BAU case is included below in Table 65 and Figure 31. Although the Electrified Option eliminates natural gas use by 2050, there is still a natural gas cost included in the LCCA from natural gas use between 2022-2050 before all buildings have been electrified. Additional details on the LCCA are included in Appendix E.

Table 65: ABRSD – LCCA Results

30 Year Life Cycle - Economic Comparison			
Option:	**BAU**	**Electrification Option**	**Delta**
Elec Utility Cost	$2,093,892	$3,875,115	$1,781,223
NG Utility Cost	$4,834,700	$3,603,578	-$1,231,122
Total Utility Costs	$6,928,593	$7,478,693	$550,101
Maintenance Costs	$1,668,145	$1,622,225	-$45,921
Investment Costs	$7,629,167	$22,050,759	$14,421,592
30 Year Life Cycle Cost	$16,225,904	$31,151,677	**$14,925,773**

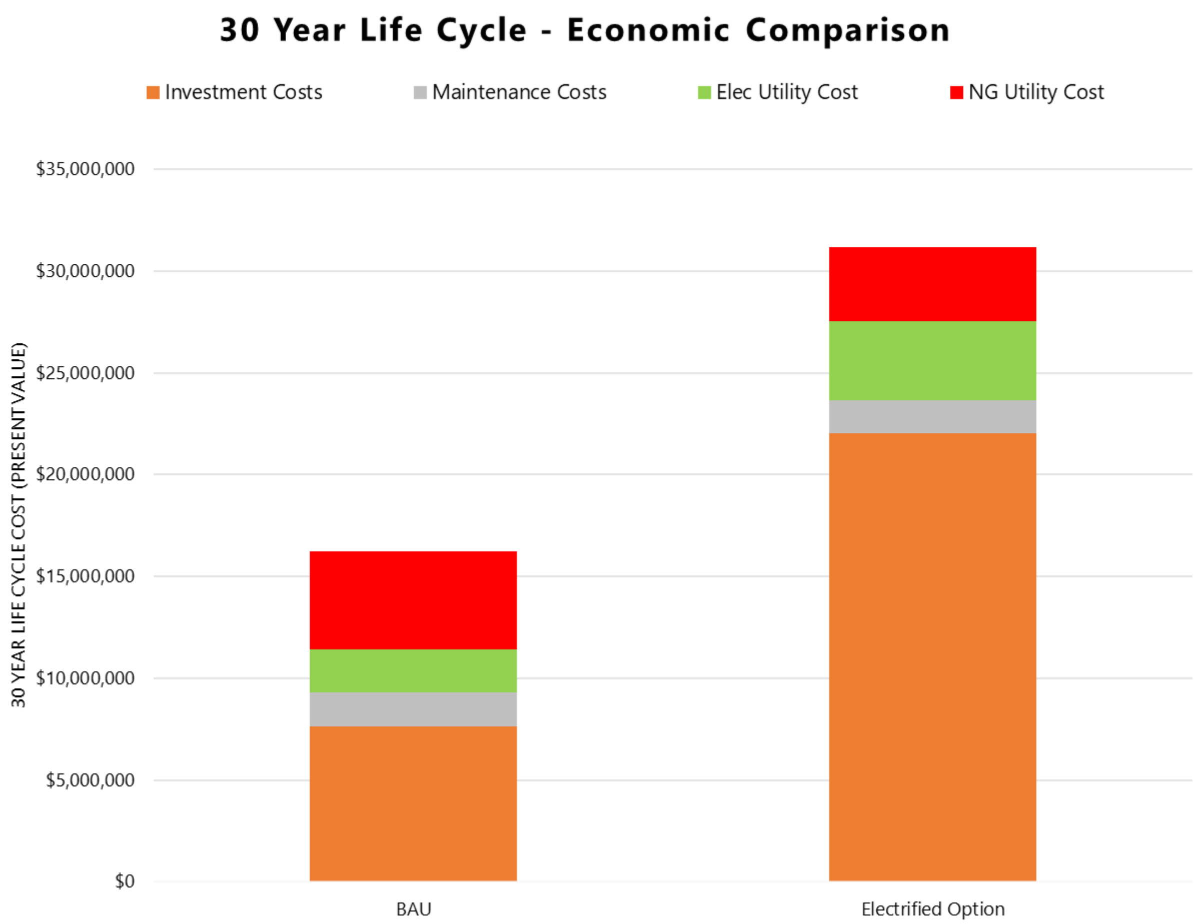


Figure 31: ABRSD LCCA Present Value Comparison

The present value of cash flow for the BAU case and the proposed electrified systems option is shown in Figure 32 below. Compared to the BAU case, there is no break even point during the 30-year LCCA. Over the 30-year LCCA, the proposed electrified systems option costs $14.9M over the BAU case.

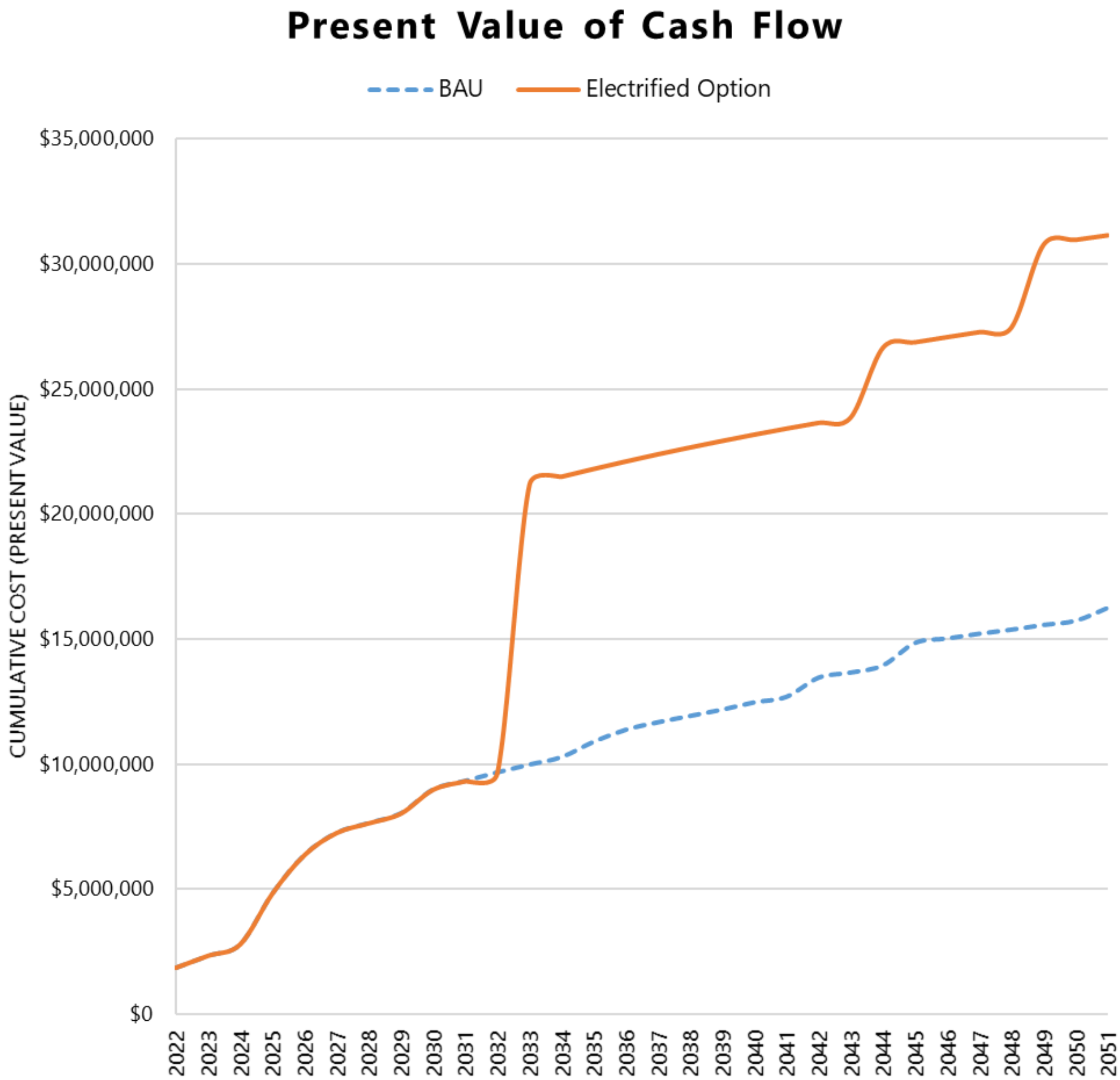


Figure 32: ABRSD LCCA Present Value Cash Flow

The major driver of the increased cost between the Electrified Option and the BAU case is the capital cost which could be substantially reduced by support from state and federal grants. The ABRSD projected operating costs, including maintenance and utility costs, increase with building electrification. The projected annual operating costs for the completed electrified option (2051) are seen in 2022 dollars in Table 66 and reflect an annual cost increase of $151,723.

Table 66: ABRSD – Operational Costs Comparison

2051 Annual Operating Costs - Economic Comparison			
	BAU	**Electrification Option**	**Delta**
Elec Utility Cost	$122,770	$548,546	$425,776
NG Utility Cost	$280,353	$0	-$280,353
Maintenance Costs	$98,000	$103,300	$5,300
Total Operational Costs	$501,123	$651,846	$151,723

Relative GHG Performance

The GHG performance for the BAU case and Electrified Option were evaluated and are detailed in Figure 34 and Figure 33. These figures illustrate the phasing out of natural gas as each building is electrified and show the effects of the greening of the electrical grid through 2050.

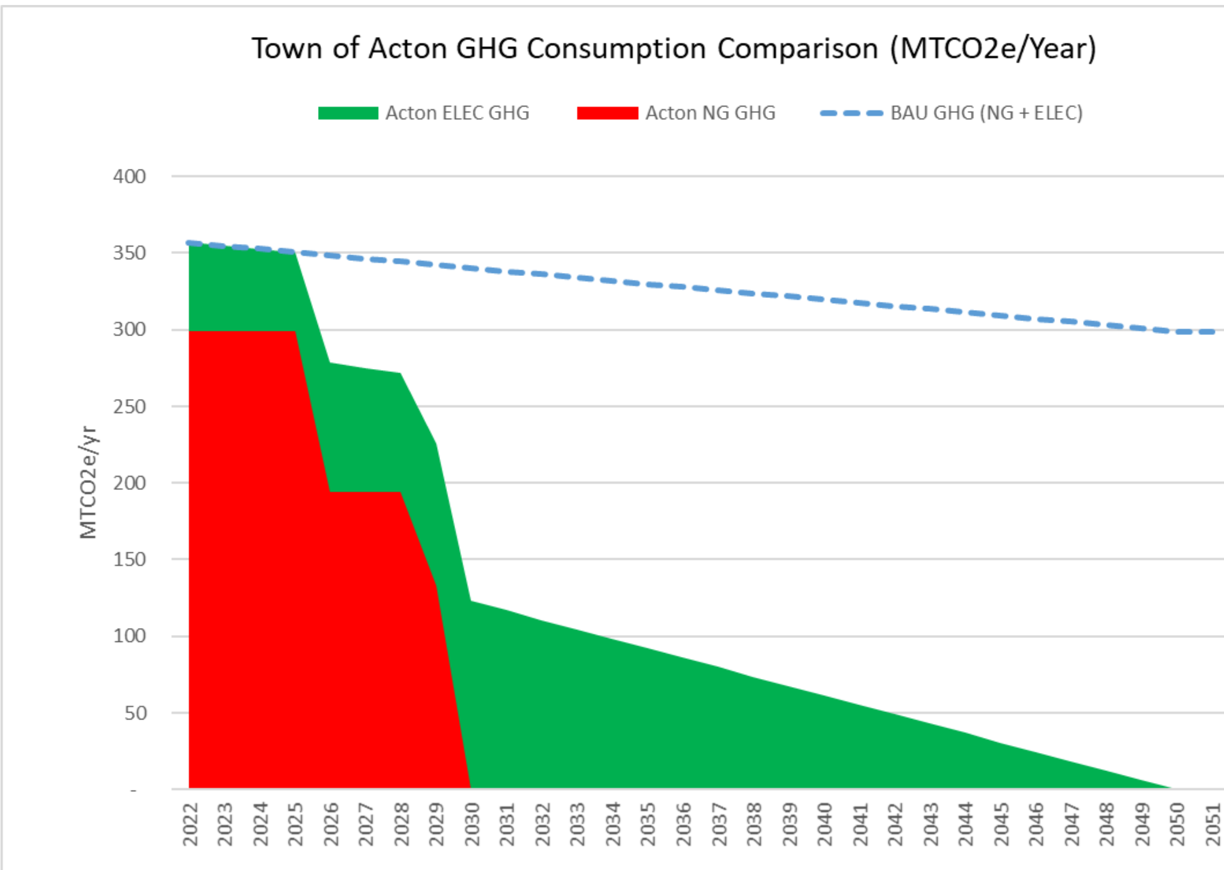


Figure 33: GHG Emissions for Town of Acton Buildings 2022-2051

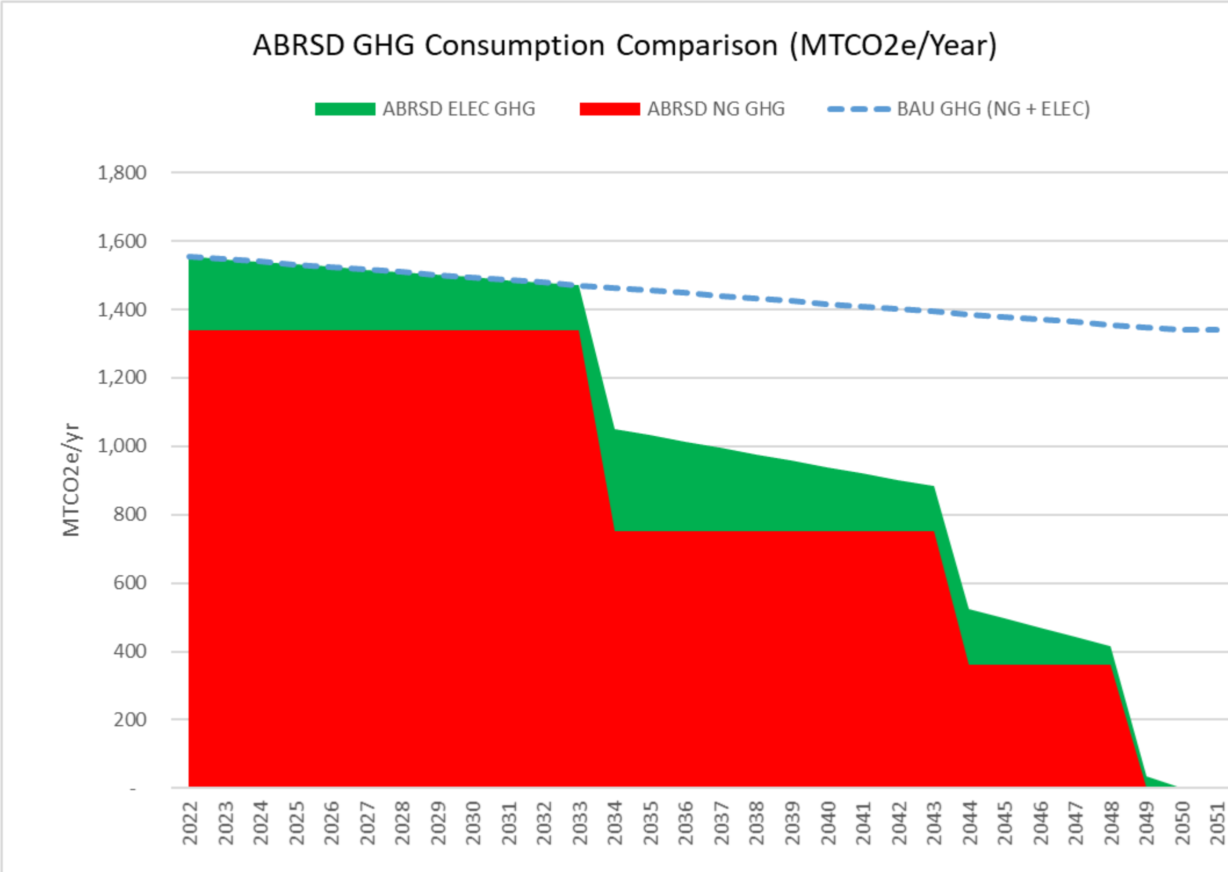


Figure 34: GHG Consumption for ABRSD Buildings 2022-2051

By switching to the recommended electrified systems, the total avoided GHG emissions for the Town of Acton and ABRSD buildings is 19,157 MTCO2e between 2022-2051, which is equivalent to the consumption of 46,000 barrels of oil[v].

The analysis of GHG emissions reduction is based on the Massachusetts energy grid, which is made up of a mix of renewable and non-renewable sources. The Town of Acton sources renewable electricity for nearly all of its municipal buildings with Acton Power Choice 100% GREEN, which entails purchasing Renewable Energy Certificates (RECs) from clean energy projects in the Northeast. The amount of RECs purchased is equal to the amount of electricity consumed by the buildings, achieving net-zero emissions in the Town of Acton's electricity use. Electricity for the Memorial Library, Town Hall, and the PSF is sourced 100% renewably by purchasing national wind RECs via a contract with First Point Power.

The Acton Boxborough Regional School District specifies 100% renewably sourced electricity as part of its supply contract covering all Eversource electricity consumed. This specification is met through the purchase of national wind Renewable Energy Certificates (RECs).

Conclusion/Recommendations

The electrification options for HVAC systems across all buildings studied result in reduced annual energy use and reduced GHG emissions, including the elimination of all GHG emissions associated with natural gas. The Electrification Roadmap recommendations will require a significant investment in capital costs and will increase annual energy costs. While the electrification options reduce overall annual energy use compared to BAU scenarios, they also result in increased annual energy costs as electricity is currently more expensive than natural gas on a per energy unit basis. Electrification of the seven buildings outlined in this report is an important part of moving forward on the Town of Acton's Climate Emergency Declaration to eliminate carbon emissions by 2030 and is aligned with the aggressive energy conservation mindset demonstrated by the Acton-Boxborough Regional School District.

This roadmap is intended to guide the strategic direction and decision-making processes that will impact building operations and infrastructure for these seven buildings, as well as support accelerated electrification and decarbonization in municipal & school operations. The Electrification Roadmap can also be useful in identifying pathways for electrifying beyond municipal and school buildings, as these electrification options are applicable to the residential and commercial buildings within the Town of Acton and surrounding communities as well.

The planning and implementation of this electrification process will require sustained effort from now through 2050. This plan will help position both the Town of Acton and ABRSD for funding opportunities to work with its partners to plan, fund and implement the electrification transformation outlined in this report. State and federal funding is needed to bring down capital costs so that the Town of Acton and ABRSD can move forward on meeting the state net zero by 2050 goal and the Town of Acton net zero by 2030 target.

Addressing climate change by moving away from fossil fuels is important to the Town of Acton's residents and is essential in meeting the state goal to aggressively retrofit the state's building stock. There are substantial economic and public health benefits to not burning fossil fuels beyond those noted in the analysis, including cleaner air, a reduction in respiratory illnesses, and work absences avoided. The Massachusetts 2050 Decarbonization Roadmap calculates $2.2 billion in total health benefits from the electrification of heating by 2050[vi]. By implementing the Electrification Roadmap, the Town of Acton and ABRSD will also be better equipped to capture incentives and avoid policy penalties linked to burning fossil fuels, such as a statewide carbon tax. The transition from fossil fuels towards electrified systems relying on renewable grid electricity is workable, and the steps outlined within this study provide a feasible roadmap to achieve this transition, setting the example for other municipalities and school districts in Massachusetts and beyond.

Next Steps

If the Town of Acton and ABRSD elect to move forward with elements of the Electrification Roadmap, the following next steps can help prioritize electrification efforts and prepare the buildings for the conversion process outlined above. With the first phase of the Electrification Roadmap starting in 2025 for the Town of Acton and in 2033 for the ABRSD, now is the time to focus on how to plan and fund this transition.

1. Energy Conservation Measures
    a. Identify and implement ECMs to reduce building energy use and GHG emissions.
    b. Ensure that any building renovations, deferred maintenance, and routine maintenance measures support efficiency and the adoption of low temperature hot water heating. Examples include:
        - Window repair and replacement windows
        - Building envelope improvements
        - Radiation (heating) designed to support low temperature hot water
        - Controls upgrades

2. Where natural gas-fired building systems fail sooner than expected, accelerate the implementation of this roadmap.

3. At the Administration Building, where central air conditioning may be added, ensure that it is compatible with future heat pump technology.

4. Participate in all utility rebate programs and consider additional projects for efficiency.

5. Communicate the findings of this Electrification Roadmap report to all relevant utility companies and constituents to gain awareness and support.

6. Coordinate with utility companies to support investment and planning in infrastructure upgrades to support electrification and any needed building electrical upgrades.

7. Identify potential funding sources including utility incentives (both prescriptive and custom), federal and state sources, non-profit grants, donors, and third-party financing options.

Appendix

Appendix A: BAU Capital Cost Summary

- A1: Town of Acton BAU Capital Cost Summary
- A2: ABRSD BAU Capital Cost Summary

Appendix B: Maintenance Costs

- B1: Town of Acton Annual Maintenance Costs
- B2: Town of Acton Annual Maintenance Costs – Electrification Option
- B3: ABRSD Annual Maintenance Costs
- B4: ABRSD Annual Maintenance Costs – Electrification Option

Appendix C: Building Conversion Costs for LTHW

Appendix D: Energy Plant Costs

- D1: Acton Town Hall Energy Plant Cost Estimate
- D2: Acton Memorial Library Energy Plant Cost Estimate
- D3: Public Safety Facility Energy Plant Cost Estimate
- D4: ABRHS Energy Plant Cost Estimate
- D5: ABRHS GSHP Energy Plant Cost Estimate
- D6: RJ Grey Energy Plant Cost Estimate
- D7: Parker Damon Energy Plant Cost Estimate
- D8: Administration Building Energy Plant Cost Estimate

Appendix E: LCCA Summary Tables

- E1: Town of Acton LCCA Summary Table - BAU
- E2: Town of Acton LCCA Summary Table – Electrified Option
- E3: ABRSD LCCA Summary Table – BAU
- E4: ABRSD LCCA Summary Table – Electrified Option

Appendix F: Alternative Energy Credit Calculation Summary

References

[i] Massachusetts Executive Office of Energy and Environmental Affairs, Massachusetts 2050 Decarbonization Roadmap, December 2020: https://www.mass.gov/doc/ma-2050-decarbonization-roadmap/download;

[ii] https://www.masssave.com/saving/business-rebates/ci-heat-pump

[iii] https://www.mass.gov/doc/guideline-on-metering-and-calculating-useful-thermal-output-of-eligible-renewable-thermal/download

[iv] EPA. (2017) The Social Cost of Carbon https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html

[v] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

[vi] Massachusetts Executive Office of Energy and Environmental Affairs, Massachusetts 2050 Decarbonization Roadmap, December 2020 https://www.mass.gov/doc/ma-2050-decarbonization-roadmap/download

Appendix A1: Capital Cost Summary

	Town of Acton				
	AML	Town Hall	PSF	Total	Comments
2022	$ -	$ -	$ 280,506	$ 280,506	PSF AHU & Split System Replacement
2023	$ -	$ -	$ -	$ -	
2024	$ -	$ -	$ -	$ -	
2025	$ -	$ -	$ -	$ -	
2026	$ -	$ -	$ -	$ -	
2027	$ -	$ -	$ -	$ -	
2028	$ -	$ -	$ -	$ -	
2029	$ -	$ 19,289	$ -	$ 19,289	Town Hall Split System Replacement
2030	$ -	$ -	$ 54,459	$ 54,459	PSF Boiler Replacement
2031	$ -	$ -	$ -	$ -	
2032	$ -	$ -	$ -	$ -	
2033	$ 313,844	$ -	$ -	$ 313,844	AML RTU Replacement
2034	$ -	$ -	$ -	$ -	
2035	$ -	$ -	$ -	$ -	
2036	$ -	$ -	$ -	$ -	
2037	$ -	$ -	$ 280,506	$ 280,506	PSF AHU & Split System Replacement
2038	$ -	$ 127,600	$ -	$ 127,600	Town Hall Chiller Replacement
2039	$ -	$ -	$ -	$ -	
2040	$ -	$ -	$ -	$ -	
2041	$ -	$ -	$ -	$ -	
2042	$ 61,709	$ -	$ -	$ 61,709	AML Boiler Replacement
2043	$ -	$ -	$ -	$ -	
2044	$ -	$ 19,289	$ -	$ 19,289	Town Hall Split System Replacement
2045	$ -	$ -	$ -	$ -	
2046	$ -	$ -	$ -	$ -	
2047	$ -	$ -	$ -	$ -	
2048	$ 313,844	$ -	$ -	$ 313,844	AML RTU Replacement
2049	$ -	$ -	$ -	$ -	
2050	$ -	$ -	$ -	$ -	
2051	$ -	$ -	$ -	$ -	

Appendix A2: Capital Cost Summary

	Acton-Boxborough Regional School District					
	Admin	Parker Damon	RJ Grey	ABRHS	Total	Comments
2022	$ 24,409	$ 403,074	$ 167,169	$ 769,225	$ 1,363,877	Admin Window ACs, Parker Damon RTUs, RJ Grey Split Systems
2023	$ -	$ -	$ -	$ -	$ -	
2024	$ -	$ -	$ -	$ -	$ -	
2025	$ -	$ -	$ 27,460	$ 1,784,602	$ 1,812,062	RJ Grey Window Acs, ABRHS RTUs
2026	$ -	$ 1,333,891	$ -	$ -	$ 1,333,891	Parker Damon Chillers and Unit Ventilators
2027	$ 61,538	$ -	$ 536,138	$ -	$ 597,676	Admin AHUs, RJ Grey Unit Ventilators
2028	$ -	$ -	$ -	$ -	$ -	
2029	$ 24,409	$ -	$ -	$ -	$ 24,409	Admin Window Acs
2030	$ 57,866	$ -	$ -	$ 791,881	$ 849,747	Admin Split Systems, ABRHS Chiller, Unit Ventilators and VAVs
2031	$ -	$ -	$ -	$ -	$ -	
2032	$ -	$ -	$ 27,460	$ -	$ 27,460	RJ Grey Window Acs
2033	$ -	$ -	$ -	$ -	$ -	
2034	$ -	$ -	$ -	$ -	$ -	
2035	$ -	$ -	$ -	$ 578,206	$ 578,206	ABRHS Boiler
2036	$ 24,409	$ 109,080	$ 246,836	$ -	$ 380,325	Admin Window Acs, Parker Damon FTR, RJ Grey RTUs
2037	$ -	$ -	$ 72,720	$ -	$ 72,720	RJ Grey FTR
2038	$ -	$ -	$ -	$ -	$ -	
2039	$ -	$ -	$ 27,460	$ -	$ 27,460	RJ Grey Window AC
2040	$ -	$ -	$ -	$ 136,350	$ 136,350	ABRHS FTR
2041	$ -	$ -	$ -	$ -	$ -	
2042	$ -	$ 403,074	$ 167,169	$ 769,225	$ 1,339,468	Parker Damon RTUs, RJ Grey Split Systems, ABRHS RTUs
2043	$ -	$ -	$ -	$ -	$ -	
2044	$ -	$ -	$ 246,836	$ -	$ 246,836	RJ Grey Boilers
2045	$ -	$ 170,285	$ -	$ 1,784,602	$ 1,954,887	Parker Damon Boilers, ABRHS RTUs
2046	$ -	$ -	$ -	$ -	$ -	
2047	$ 61,538	$ -	$ -	$ -	$ 61,538	Admin AHUs
2048	$ -	$ -	$ -	$ -	$ -	
2049	$ 108,918	$ -	$ -	$ -	$ 108,918	Admin Boiler
2050	$ 57,866	$ -	$ -	$ -	$ 57,866	Admin Split Systems
2051	$ -	$ 1,333,891	$ -	$ -	$ 1,333,891	Parker Damon Chillers and Unit Ventilators

Appendix B1: Town of Acton Annual Maintenance Costs								
	BAU				Recommended Option			
	Acton Town Hall	Acton Memorial Library	Public Safety Facility	Total	Acton Town Hall	Acton Memorial Library	Public Safety Facility	Total
2022	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 16,211	$ 26,341	$ 34,863	$ 77,415
2023	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 16,211	$ 26,341	$ 34,863	$ 77,415
2024	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 16,211	$ 26,341	$ 34,863	$ 77,415
2025	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 16,211	$ 26,341	$ 18,580	$ 61,132
2026	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 16,211	$ 26,341	$ 18,580	$ 61,132
2027	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 16,211	$ 26,341	$ 18,580	$ 61,132
2028	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 26,341	$ 18,580	$ 55,096
2029	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2030	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2031	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2032	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2033	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2034	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2035	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2036	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2037	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2038	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2039	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2040	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2041	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2042	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2043	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2044	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2045	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2046	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2047	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2048	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2049	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2050	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400
2051	$ 16,211	$ 26,341	$ 34,863	$ 77,415	$ 10,175	$ 17,645	$ 18,580	$ 46,400

Appendix B2: Town of Acton Annual Maintenance Costs - Electrification Option

Acton Town Hall Maintenance Costs		
Item	Cost	Notes
ASHP	$ 3,750	$50/Ton and 75 Tons installed
FCU	$ 1,875	$25/Ton and 75 Tons installed
Misc	$ 4,550	Additional building maintenance also included in BAU budget
Total	$ 10,175	

Acton Memorial Library Maintenance Costs		
Item	Cost	Notes
ASHP	$ 5,750	$50/Ton and 115 Tons installed
Electric Boiler	$ 2,500	$2,500 per boiler
RTU	$ 2,875	$25/Ton and 115 Tons installed
Misc	$ 6,520	Additional building maintenance also included in BAU budget
Total	$ 17,645	

Public Safety Facility Maintenance Costs		
Item	Cost	Notes
ASHP	$ 4,500	$50/Ton and 90 Tons installed
AHU	$ 2,250	$25/Ton and 90 Tons installed
Misc	$ 11,830	Additional building maintenance also included in BAU budget
Total	$ 18,580	

Appendix B3: ABRSD Annual Maintenance Costs

	BAU					Recommended Option				
	ABRHS	RJ Grey	Parker Damon	Admin Building	Total	ABRHS	RJ Grey	Parker Damon	Admin Building	Total
2022	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000
2023	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000
2024	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000
2025	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000
2026	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000
2027	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000
2028	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000
2029	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000
2030	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000
2031	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000
2032	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000
2033	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 19,600	$ 19,600	$ 4,900	$ 92,600
2034	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 19,600	$ 19,600	$ 4,900	$ 92,600
2035	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 19,600	$ 19,600	$ 4,900	$ 92,600
2036	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 19,600	$ 19,600	$ 4,900	$ 92,600
2037	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 19,600	$ 19,600	$ 4,900	$ 92,600
2038	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 19,600	$ 19,600	$ 4,900	$ 92,600
2039	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 19,600	$ 19,600	$ 4,900	$ 92,600
2040	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 19,600	$ 19,600	$ 4,900	$ 92,600
2041	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 19,600	$ 19,600	$ 4,900	$ 92,600
2042	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 19,600	$ 19,600	$ 4,900	$ 92,600
2043	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 19,600	$ 19,600	$ 4,900	$ 92,600
2044	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 13,000	$ 19,600	$ 4,900	$ 86,000
2045	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 13,000	$ 19,600	$ 4,900	$ 86,000
2046	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 13,000	$ 19,600	$ 4,900	$ 86,000
2047	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 13,000	$ 19,600	$ 4,900	$ 86,000
2048	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 13,000	$ 19,600	$ 4,900	$ 86,000
2049	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 13,000	$ 30,550	$ 11,250	$ 103,300
2050	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 13,000	$ 30,550	$ 11,250	$ 103,300
2051	$ 53,900	$ 19,600	$ 19,600	$ 4,900	$ 98,000	$ 48,500	$ 13,000	$ 30,550	$ 11,250	$ 103,300

Appendix B4: ABRSD Annual Maintenance Costs - Electrification Option

ABRHS Maintenance Costs		
Item	Cost	Notes
ASHP	$ 21,000	$50/Ton and 420 Tons installed
ACCH	$ 9,500	$50/Ton and 190 Tons installed
Electric Boiler	$ 2,500	$2,500 per boiler
Solar Thermal	$ 250	$250 per 1,500 SF collector
RTU	$ 15,250	$25/Ton and 610 Tons installed
Total	$ 48,500	

RJ Grey Maintenance Costs		
Item	Cost	Notes
ASHP	$ 7,000	$50/Ton and 140 Tons installed
Electric Boiler	$ 2,500	$2,500 per boiler
RTU	$ 3,500	$25/Ton and 140 Tons installed
Total	$ 13,000	

Parker Damon Maintenance Costs		
Item	Cost	Notes
ASHP	$ 7,500	$50/Ton and 150 Tons installed
ACCH	$ 11,200	$50/Ton and 224 Tons installed
Electric Boiler	$ 2,500	$2,500 per boiler
RTU	$ 9,350	$25/Ton and 374 Tons installed
Total	$ 30,550	

Admin Building Maintenance Costs		
Item	Cost	Notes
ASHP	$ 7,500	$50/Ton and 150 Tons installed
AHU	$ 3,750	$25/Ton and 150 Tons installed
Total	$ 11,250	

Appendix C: Building Conversion Costs for LTHW

Building Name	Bldg. Conversion (H/M/L)	Gross Area (SF)	Conversion Year	Conversion Costs ($)	Estimated $ / GSF *		
					Low	Medium	High
Town of Acton					$10.00	$22.00	$35.00
Acton Memorial Library	H	48,259	2029	$1,689,065			
Acton Town Hall	H	24,144	2028	$845,040			
Public Safety Facility	H	26,033	2025	$911,155			
Total		98,436		$3,445,260			
Acton Boxborough Regional School District							
Acton Boxborough Regional High School	H	386,000	2033	$13,510,000			
Administration Building	H	36,000	2049	$1,260,000			
Parker Damon	H	142,000	2049	$4,970,000			
RJ Grey Junior High	H	143,000	2044	$5,005,000			
Total		707,000		$24,745,000			

Building Conversion Effort Notes:

Acton Memorial Library -
Rooftop HVAC Units w/ DX Cooling, Natural Gas Heating, Hydronic Heating Systems, Historic, Older Building, Only building type in community

Acton Town Hall -
FCUs w/ Air Cooled Chiller, Split DX Air Conditioners, Natural Gas Heating, Hydronic Heating Systems, Historic, Older Building, Only building type in community

Public Safety Facility -
24/7 Critical Facility, DX Cooling, Natural Gas Heating, Hydronic Heating Systems, Newer Construction, Community Shelter, Only building type in community

Acton Boxborough Regional High School -
Large building, Community Shelter, Only building type in community, Rooftop HVAC units w/ DX Cooling, Some Rooftop HVAC Units are Natural Gas, Natural Gas Heating, Hydronic Heating Systems, Natatorium

Administration Building -
Older Building, No Central Air Conditioning, Split DX Air Conditioners, Window AC Units

Parker Damon -
Large building, Rooftop HVAC Units w/ DX Cooling, Chilled Water FCUS, Natural Gas Heating, Hydronic Heating Systems

RJ Grey Junior High -
Large building, Rooftop HVAC Units w/ DX Cooling, Split DX Air Conditioners, Window AC Units, Natural Gas Heating, Hydronic Heating Systems

*costs include owner's costs, design & construction contingencies

Appendix D1: Acton Town Hall Energy Plant Cost Estimate

Town Hall Cost Estimate					
SIZE	TYPE	UNIT	QTY	UNIT PRICE	TOTAL PRICE
8"	PIPING	LF	0	$ 226.42	$ -
6"	PIPING	LF	0	$ 167.02	$ -
4"	PIPING	LF	0	$ 105.52	$ -
3"	PIPING	LF	150	$ 85.19	$ 13,000
2"	PIPING	LF	100	$ 75.00	$ 8,000
MISC COSTS (VALVES, FITTINGS, ACCESSORIES, ETC.)		EACH	1	25%	$ 5,250
Air Source Heat Pumps - Equipment Cost		TON	75	$ 1,950	$ 147,000
Air Source Heat Pumps - Installation		TON	75	$ 1,950	$ 147,000
Pumps (3 hp) - dual service LTHW, CHW		EACH	2	$ 5,600	$ 12,000
MISC ACCESSORIES		EACH	1	$ 100,000	$ 100,000
ELECTRICAL					
Mechanical Equipment installation & disconnections		EACH	1	$ 45,000	$ 45,000
Replacement of MDP with matching breakers		EACH	1	$ 28,000	$ 28,000
Replacement Generator to 100kW		EACH	1	$ 75,000	$ 75,000
Replacement of panelboard ELG		EACH	1	$ 9,000	$ 9,000
Controls		EACH	1	$ 150,000	$ 150,000
TOTAL DIRECT COST OF WORK					$ 739,250

Design / Estimating / Contingency	15%	$ 110,888
Construction Contingency	10%	$ 73,925
General Conditions	10%	$ 73,925
Insurance / Bond	3.75%	$ 27,722
Building Permit	1%	$ 7,393
Contractor Fee	10%	$ 73,925

TOTAL	$ 1,107,000

Contingency Definitions:
Design / Estimating / Contingency: All design fees, cost estimation fees with associated contingency included to cover increased design and cost estimation fees
Construction Contingency: Construction cost variance from estimations
General Conditions: Items and resources needed for project completion, including garbage removal, temporary offices and protection, and administrative time

Appendix D2: Acton Memorial Library Energy Plant Cost Estimate

Memorial Library Cost Estimate					
SIZE	TYPE	UNIT	QTY	UNIT PRICE	TOTAL PRICE
8"	PIPING	LF	0	$ 226.42	$ -
6"	PIPING	LF	300	$ 167.02	$ 51,000
4"	PIPING	LF	150	$ 105.52	$ 16,000
3"	PIPING	LF	100	$ 85.19	$ 9,000
2"	PIPING	LF	0	$ 75.00	$ -
MISC COSTS (VALVES, FITTINGS, ACCESSORIES, ETC.)		EACH	1	25%	$ 19,000
Air Source Heat Pumps - Equipment Cost		TON	115	$ 1,950	$ 225,000
Air Source Heat Pumps - Installation		TON	115	$ 1,950	$ 225,000
Electric Boiler (680 MBH)		EACH	1	$ 31,200	$ 32,000
Pumps (7.5 hp) - dual service LTHW, CHW		EACH	2	$ 11,600	$ 24,000
MISC ACCESSORIES		EACH	1	$ 100,000	$ 100,000
ELECTRICAL					
Mechanical Equipment installation & disconnections		EACH	1	$ 82,000	$ 82,000
Replacement Generator to 125 kW		EACH	1	$ 78,000	$ 78,000
Replacement of panelboard LNE-1		EACH	1	$ 9,000	$ 9,000
Controls		EACH	1	$ 150,000	$ 150,000
TOTAL DIRECT COST OF WORK					$ 1,020,000

Design / Estimating / Contingency	15%	$ 153,000
Construction Contingency	10%	$ 102,000
General Conditions	10%	$ 102,000
Insurance / Bond	3.75%	$ 38,250
Building Permit	1%	$ 10,200
Contractor Fee	10%	$ 102,000

TOTAL	$ 1,527,000

Appendix D3: Public Safety Facility Energy Plant Cost Estimate

Public Safety Facility Cost Estimate					
SIZE	TYPE	UNITS	QTY	UNIT PRICE	TOTAL PRICE
8"	PIPING	LF	0	$ 226.42	$ -
6"	PIPING	LF	0	$ 167.02	$ -
4"	PIPING	LF	400	$ 105.52	$ 43,000
3"	PIPING	LF	750	$ 85.19	$ 64,000
2"	PIPING	LF	0	$ 75.00	$ -
MISC COSTS (VALVES, FITTINGS, ACCESSORIES, ETC.)		EACH	1	25%	$ 26,750
Air Source Heat Pumps - Equipment Cost		TONS	90	$ 1,950	$ 176,000
Air Source Heat Pumps - Installation		TONS	90	$ 1,950	$ 176,000
Pumps (5 hp) - dual service LTHW, CHW		EACH	2	$ 9,900	$ 20,000
MISC ACCESSORIES		EACH	1	$ 100,000	$ 100,000
ELECTRICAL					
Mechanical Equipment installation & disconnections		EACH	1	$ 45,000	$ 45,000
Replacement of panelboard SB2		EACH	1	$ 28,000	$ 28,000
Replacement Generator to 350 kW		EACH	1	$ 135,000	$ 135,000
Controls		EACH	1	$ 150,000	$ 150,000
TOTAL DIRECT COST OF WORK					$ 963,750

Design / Estimating / Contingency	15%	$ 144,563
Construction Contingency	10%	$ 96,375
General Conditions	10%	$ 96,375
Insurance / Bond	3.75%	$ 36,141
Building Permit	1%	$ 9,638
Contractor Fee	10%	$ 96,375

TOTAL	$ 1,443,000

Appendix D4: ABRHS Energy Plant Cost Estimate - ASHP

ABRHS Energy Plant Cost Estimate - ASHP					
SIZE	TYPE	UNITS	QTY	UNIT PRICE	TOTAL PRICE
8"	PIPING	LF	200	$ 226.42	$ 46,000
6"	PIPING	LF	200	$ 167.02	$ 34,000
4"	PIPING	LF	200	$ 105.52	$ 22,000
3"	PIPING	LF	250	$ 85.19	$ 22,000
2"	PIPING	LF	250	$ 75.00	$ 19,000
MISC COSTS (VALVES, FITTINGS, ACCESSORIES, ETC.)		EACH	1	25%	$ 35,750
Air Source Heat Pumps - Equipment Cost		TONS	420	$ 1,950	$ 819,000
Air Source Heat Pumps - Installation		TONS	420	$ 1,950	$ 819,000
Air Cooled Chiller - Equipment Cost		TONS	190	$ 900	$ 171,000
Air Cooled Chiller - Installation		TONS	190	$ 900	$ 171,000
Electric Boiler (2200 MBH)		EACH	1	$ 87,368	$ 88,000
Solar Thermal Collector System		EACH	1	$ 240,000	$ 240,000
Pumps (3 hp) - Solar Thermal		EACH	2	$ 5,600	$ 12,000
Pumps (15 hp) - CHW/LTHW		EACH	2	$ 12,380	$ 25,000
MISC ACCESSORIES		EACH	1	$ 100,000	$ 100,000
ELECTRICAL					
Mechanical Equipment installation & disconnections		EACH	1	$ 82,000	$ 82,000
New Service Entrance and associated equipment		EACH	1	$ 64,000	$ 64,000
Replacement generator of 750 kW		EACH	1	$ 185,000	$ 185,000
Replacement of Panelboard MEDP		EACH	1	$ 34,000	$ 34,000
Controls		EACH	1	$ 150,000	$ 150,000
TOTAL DIRECT COST OF WORK					$ 3,138,750

Design / Estimating / Contingency	15%	$ 470,813
Construction Contingency	10%	$ 313,875
General Conditions	10%	$ 313,875
Insurance / Bond	3.75%	$ 117,703
Building Permit	1%	$ 31,388
Contractor Fee	10%	$ 313,875

TOTAL	$ 4,700,000

Appendix D5: ABRHS Building Energy Plant Cost Estimate - Geothermal

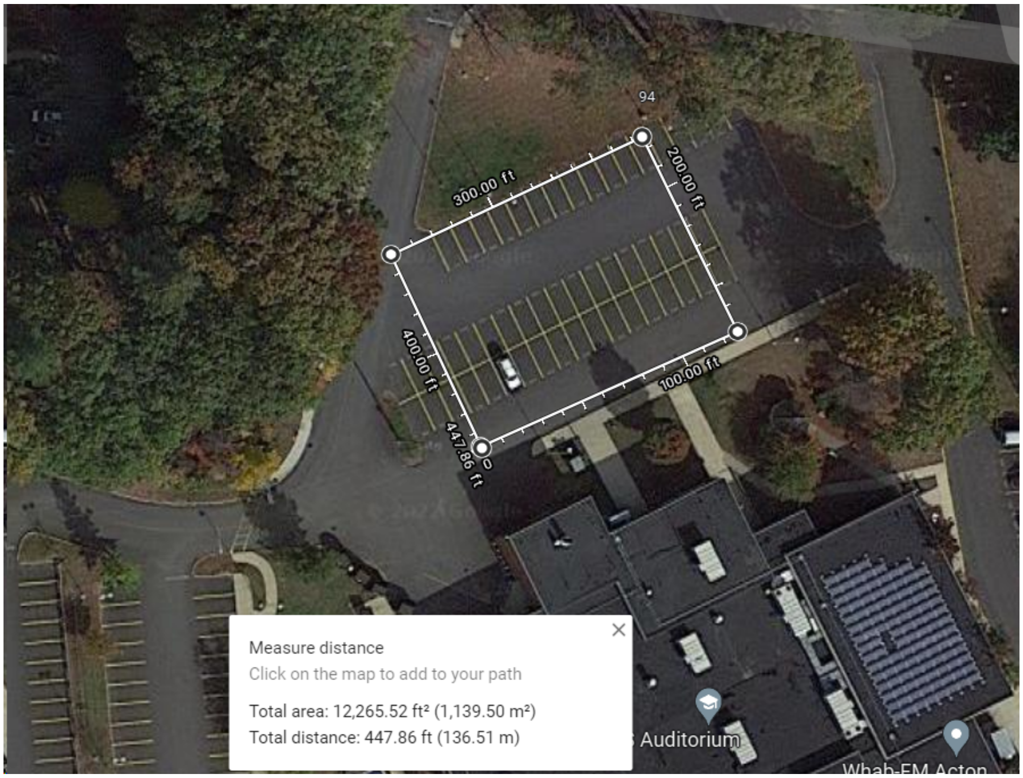
ABRHS Energy Plant Cost Estimate - GEO					
SIZE	TYPE	UNITS	QTY	UNIT PRICE	TOTAL PRICE
8"	PIPING	LF	200	$ 226.42	$ 46,000
6"	PIPING	LF	200	$ 167.02	$ 34,000
4"	PIPING	LF	200	$ 105.52	$ 22,000
3"	PIPING	LF	250	$ 85.19	$ 22,000
2"	PIPING	LF	250	$ 75.00	$ 19,000
MISC COSTS (VALVES, FITTINGS, ACCESSORIES, ETC.)		EACH	1	25%	$ 35,750
Air Source Heat Pumps - Equipment Cost		TONS	320	$ 1,950	$ 624,000
Air Source Heat Pumps - Installation		TONS	320	$ 1,950	$ 624,000
Heat Pump Chiller - Equipment Cost		TONS	60	$ 1,000	$ 60,000
Heat Pump Chiller - Installation		TONS	60	$ 1,000	$ 60,000
Borefield		BORE	30	$ 40,000	$ 1,200,000
Air Cooled Chiller - Equipment Cost		TONS	190	$ 900	$ 171,000
Air Cooled Chiller - Installation		TONS	190	$ 900	$ 171,000
Electric Boiler (2200 MBH)		EACH	1	$ 87,368	$ 88,000
Solar Thermal Collector System		EACH	1	$ 240,000	$ 240,000
Pumps (3 hp) - Solar Thermal		EACH	2	$ 5,600	$ 12,000
Pumps (15 hp) - CHW/LTHW		EACH	2	$ 12,380	$ 25,000
Pumps (15 hp) - GEO		EACH	2	$ 12,380	$ 25,000
MISC ACCESSORIES		EACH	1	$ 100,000	$ 100,000
ELECTRICAL					
Mechanical Equipment installation & disconnections		EACH	1	$ 82,000	$ 82,000
New Service Entrance and associated equipment		EACH	1	$ 64,000	$ 64,000
Replacement generator of 750 kW		EACH	1	$ 185,000	$ 185,000
Replacement of Panelboard MEDP		EACH	1	$ 34,000	$ 34,000
Controls		EACH	1	$ 150,000	$ 150,000
TOTAL DIRECT COST OF WORK					$ 4,093,750

Design / Estimating / Contingency	15%	$ 614,063
Construction Contingency	10%	$ 409,375
General Conditions	10%	$ 409,375
Insurance / Bond	3.75%	$ 153,516
Building Permit	1%	$ 40,938
Contractor Fee	10%	$ 409,375
TOTAL		$ 6,130,000

Add Cost over ASHP	$ 1,430,000
Annual Energy Cost Savings over ASHP	$ 19,516
Simple Paybackover ASHP (years)	73

ABRHS Geothermal Borefield Location Options
(30 Bores/12,000 SF Required)

Parking Lot North of ABRHS:



Parking Lot Landscaping North of ABRHS:

Appendix D6: RJ Grey Energy Plant Cost Estimate

RJ Grey Energy Plant Cost Estimate								
SIZE	TYPE	UNITS	QTY	UNIT PRICE		TOTAL PRICE	
8"	PIPING	LF	0	$	226.42	$	-
6"	PIPING	LF	0	$	167.02	$	-
4"	PIPING	LF	150	$	105.52	$	16,000
3"	PIPING	LF	200	$	85.19	$	18,000
2"	PIPING	LF	250	$	75.00	$	19,000
MISC COSTS (VALVES, FITTINGS, ACCESSORIES, ETC.)		EACH	1		25%	$	13,250
Air Source Heat Pumps - Equipment Cost		TONS	140	$	1,950	$	273,000
Air Source Heat Pumps - Installation		TONS	140	$	1,950	$	273,000
Electric Boiler (1250 MBH)		EACH	1	$	48,538	$	49,000
Pumps (3 hp) - ASHP		EACH	2	$	5,600	$	12,000
Pumps (10 hp) - CHW/LTHW		EACH	2	$	12,380	$	25,000
MISC ACCESSORIES		EACH	1	$	100,000	$	100,000
Electrical							
Mechanical Equipment installation & disconnections		EACH	1	$	79,000	$	79,000
Installation of new MDP with breakers		EACH	1	$	28,000	$	28,000
Replacement Generator to 175kW		EACH	1	$	90,000	$	90,000
Installation of new panelboard EHP		EACH	1	$	9,000	$	9,000
Controls		EACH	1	$	150,000	$	150,000
TOTAL DIRECT COST OF WORK						$	1,154,250

Design / Estimating / Contingency	15%	$	173,138
Construction Contingency	10%	$	115,425
General Conditions	10%	$	115,425
Insurance / Bond	3.75%	$	43,284
Building Permit	1%	$	11,543
Contractor Fee	10%	$	115,425

TOTAL	$	1,728,000

Appendix D7: Parker Damon Building Energy Plant Cost Estimate

Parker Damon Building Energy Plant Cost Estimate					
SIZE	TYPE	UNITS	QTY	UNIT PRICE	TOTAL PRICE
8"	PIPING	LF	0	$ 226.42	$ -
6"	PIPING	LF	0	$ 167.02	$ -
4"	PIPING	LF	150	$ 105.52	$ 16,000
3"	PIPING	LF	300	$ 85.19	$ 26,000
2"	PIPING	LF	300	$ 75.00	$ 23,000
MISC COSTS (VALVES, FITTINGS, ACCESSORIES, ETC.)		EACH	1	25%	$ 16,250
Air Source Heat Pumps - Equipment Cost		TONS	150	$ 1,950	$ 293,000
Air Source Heat Pumps - Installation		TONS	150	$ 1,950	$ 293,000
Air Cooled Chiller - Equipment Cost		TONS	224	$ 900	$ 201,600
Air Cooled Chiller - Installation Cost		TONS	224	$ 900	$ 201,600
Electric Boiler (1000 MBH)		EACH	1	$ 38,830	$ 38,830
Pumps (3 hp) - ASHP		EACH	2	$ 5,600	$ 12,000
Pumps (10 hp) - CHW/HW		EACH	2	$ 12,380	$ 25,000
MISC ACCESSORIES		EACH	1	$ 100,000	$ 100,000
ELECTRICAL					
Mechanical Equipment installation & disconnections		EACH	1	$ 85,000	$ 85,000
Replacement Generator to 200 kW		EACH	1	$ 90,000	$ 90,000
Installation of new panelboard EHP		EACH	1	$ 9,000	$ 9,000
Controls		EACH	1	$ 150,000	$ 150,000
TOTAL DIRECT COST OF WORK					$ 1,580,280

Design / Estimating / Contingency	15%	$ 237,042
Construction Contingency	10%	$ 158,028
General Conditions	10%	$ 158,028
Insurance / Bond	3.75%	$ 59,261
Building Permit	1%	$ 15,803
Contractor Fee	10%	$ 158,028

TOTAL	$ 2,366,000

Appendix D8: Admin Building Energy Plant Cost Estimate

Admin Building Energy Plant Cost Estimate					
SIZE	TYPE	UNITS	QTY	UNIT PRICE	TOTAL PRICE
8"	PIPING	LF	0	$ 226.42	$ -
6"	PIPING	LF	0	$ 167.02	$ -
4"	PIPING	LF	100	$ 105.52	$ 11,000
3"	PIPING	LF	200	$ 85.19	$ 18,000
2"	PIPING	LF	200	$ 75.00	$ 15,000
MISC COSTS (VALVES, FITTINGS, ACCESSORIES, ETC.)		EACH	1	25%	$ 11,000
Air Source Heat Pumps - Equipment Cost		TONS	150	$ 1,950	$ 293,000
Air Source Heat Pumps - Installation		TONS	150	$ 1,950	$ 293,000
Pumps (10 hp) - dual service LTHW, CHW		EACH	2	$ 12,380	$ 25,000
MISC ACCESSORIES		EACH	1	$ 100,000	$ 100,000
ELECTRICAL					
Mechanical Equipment installation & disconnections		EACH	1	$ 82,000	$ 82,000
New Generator 125 kW		EACH	1	$ 73,000	$ 73,000
Controls		EACH	1	$ 150,000	$ 150,000
TOTAL DIRECT COST OF WORK					$ 1,071,000

Design / Estimating / Contingency	15%	$ 160,650
Construction Contingency	10%	$ 107,100
General Conditions	10%	$ 107,100
Insurance / Bond	3.75%	$ 40,163
Building Permit	1%	$ 10,710
Contractor Fee	10%	$ 107,100

TOTAL	$ 1,604,000

Appendix E1: Town of Acton LCCA Summary Table - BAU

Town Of Acton LCCA - BAU								
Year	**Year Count**	**Electric Utility Cost PC ($)**	**Gas Utility Cost PC ($)**	**Investment Cost PC ($)**	**Maintenance Cost PC ($)**	**Total PC ($)**	**Total FC ($)**	**Total PV ($)**
2022	1	**$37,137**	**$64,690**	**$280,506**	**$80,400**	$462,733	$462,733	$462,733
2023	2	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$186,833	$174,457
2024	3	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$191,556	$167,019
2025	4	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$196,397	$159,898
2026	5	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$201,362	$153,080
2027	6	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$206,452	$146,553
2028	7	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$211,670	$140,305
2029	8	**$37,137**	**$64,690**	**$19,289**	**$80,400**	$201,516	$239,921	$148,497
2030	9	**$37,137**	**$64,690**	**$54,459**	**$80,400**	$236,686	$288,768	$166,891
2031	10	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$228,132	$123,113
2032	11	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$233,898	$117,864
2033	12	**$37,137**	**$64,690**	**$313,844**	**$80,400**	$496,071	$650,814	$306,229
2034	13	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$245,873	$108,028
2035	14	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$252,089	$103,422
2036	15	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$258,462	$99,013
2037	16	**$37,137**	**$64,690**	**$280,506**	**$80,400**	$462,733	$670,193	$239,735
2038	17	**$37,137**	**$64,690**	**$127,600**	**$80,400**	$309,827	$460,591	$153,845
2039	18	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$278,564	$86,881
2040	19	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$285,606	$83,177
2041	20	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$292,827	$79,631
2042	21	**$37,137**	**$64,690**	**$61,709**	**$80,400**	$243,936	$400,996	$101,824
2043	22	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$307,820	$72,986
2044	23	**$37,137**	**$64,690**	**$19,289**	**$80,400**	$201,516	$348,683	$77,199
2045	24	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$323,582	$66,896
2046	25	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$331,763	$64,044
2047	26	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$340,151	$61,314
2048	27	**$37,137**	**$64,690**	**$313,844**	**$80,400**	$496,071	$942,454	$158,629
2049	28	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$357,569	$56,197
2050	29	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$366,610	$53,802
2051	30	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$375,879	$51,508
30 Year Total		**$1,114,110**	**$1,940,700**	**$1,471,045**	**$2,412,000**	**$6,937,855**	**$10,138,249**	**$3,984,771**

PC: Present Cost
FC: Future Cost
PV: Present Value

Appendix E2: Town of Acton LCCA Summary Table - Electrified Option

Town Of Acton LCCA - Electrified Option								
Year	**Year Count**	**Electric Utility Cost PC ($)**	**Gas Utility Cost PC ($)**	**Investment Cost PC ($)**	**Maintenance Cost PC ($)**	**Total PC ($)**	**Total FC ($)**	**Total PV ($)**
2022	1	**$37,137**	**$64,690**	**$280,506**	**$80,400**	$462,733	$462,733	$462,733
2023	2	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$186,833	$174,457
2024	3	**$37,137**	**$64,690**	**$0**	**$80,400**	$182,227	$191,556	$167,019
2025	4	**$37,137**	**$64,690**	**$2,354,155**	**$61,080**	$2,517,062	$2,709,447	$2,205,906
2026	5	**$62,650**	**$41,833**	**$0**	**$61,080**	$165,563	$182,884	$139,033
2027	6	**$62,650**	**$41,833**	**$0**	**$61,080**	$165,563	$187,491	$133,093
2028	7	**$62,650**	**$41,833**	**$1,952,040**	**$55,055**	$2,111,578	$2,446,638	$1,621,744
2029	8	**$79,895**	**$28,105**	**$3,216,065**	**$46,400**	$3,370,465	$4,001,931	$2,476,952
2030	9	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$191,680	$110,780
2031	10	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$196,462	$106,022
2032	11	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$201,363	$101,469
2033	12	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$206,386	$97,111
2034	13	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$211,535	$92,941
2035	14	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$216,812	$88,950
2036	15	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$222,221	$85,130
2037	16	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$227,765	$81,474
2038	17	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$233,447	$77,975
2039	18	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$239,271	$74,626
2040	19	**$110,985**	**$0**	**$387,000**	**$46,400**	$544,385	$846,940	$246,655
2041	20	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$251,359	$68,354
2042	21	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$257,629	$65,419
2043	22	**$110,985**	**$0**	**$322,500**	**$46,400**	$479,885	$803,746	$190,574
2044	23	**$110,985**	**$0**	**$529,700**	**$46,400**	$687,085	$1,179,075	$261,048
2045	24	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$277,396	$57,348
2046	25	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$284,316	$54,885
2047	26	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$291,409	$52,528
2048	27	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$298,679	$50,272
2049	28	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$306,131	$48,113
2050	29	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$313,768	$46,047
2051	30	**$110,985**	**$0**	**$0**	**$46,400**	$157,385	$321,596	$44,069
30 Year Total		***$2,858,063***	***$412,364***	***$9,041,966***	***$1,546,695***	***$13,859,088***	***$17,948,501***	***$9,482,729***

PC: Present Cost
FC: Future Cost
PV: Present Value

Appendix E3: ABRSD LCCA Summary Table - BAU

ABRSD LCCA - BAU								
Year	**Year Count**	**Electric Utility Cost PC ($)**	**Gas Utility Cost PC ($)**	**Investment Cost PC ($)**	**Maintenance Cost PC ($)**	**Total PC ($)**	**Total FC ($)**	**Total PV ($)**
2022	1	**$122,770**	**$280,353**	**$1,363,877**	**$98,000**	$1,865,000	$1,865,000	$1,865,000
2023	2	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$513,914	$479,872
2024	3	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$527,032	$459,523
2025	4	**$122,770**	**$280,353**	**$1,812,062**	**$98,000**	$2,313,185	$2,490,858	$2,027,941
2026	5	**$122,770**	**$280,353**	**$1,333,891**	**$98,000**	$1,835,014	$2,025,622	$1,539,927
2027	6	**$122,770**	**$280,353**	**$597,676**	**$98,000**	$1,098,798	$1,244,055	$883,114
2028	7	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$582,938	$386,398
2029	8	**$122,770**	**$280,353**	**$24,409**	**$98,000**	$525,532	$626,798	$387,950
2030	9	**$122,770**	**$280,353**	**$849,747**	**$98,000**	$1,350,870	$1,646,973	$951,853
2031	10	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$628,729	$339,299
2032	11	**$122,770**	**$280,353**	**$27,460**	**$98,000**	$528,583	$679,868	$342,594
2033	12	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$661,238	$311,134
2034	13	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$678,118	$297,941
2035	14	**$122,770**	**$280,353**	**$578,206**	**$98,000**	$1,079,329	$1,490,691	$611,573
2036	15	**$122,770**	**$280,353**	**$380,325**	**$98,000**	$881,448	$1,249,264	$478,575
2037	16	**$122,770**	**$280,353**	**$72,720**	**$98,000**	$573,843	$836,434	$299,201
2038	17	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$750,060	$250,532
2039	18	**$122,770**	**$280,353**	**$27,460**	**$98,000**	$528,583	$810,868	$252,902
2040	19	**$122,770**	**$280,353**	**$136,350**	**$98,000**	$637,473	$1,000,840	$291,476
2041	20	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$808,984	$219,995
2042	21	**$122,770**	**$280,353**	**$1,339,468**	**$98,000**	$1,840,591	$3,016,885	$766,068
2043	22	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$850,818	$201,735
2044	23	**$122,770**	**$280,353**	**$246,836**	**$98,000**	$747,959	$1,295,863	$286,905
2045	24	**$122,770**	**$280,353**	**$1,954,887**	**$98,000**	$2,456,010	$4,330,650	$895,299
2046	25	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$917,663	$177,147
2047	26	**$122,770**	**$280,353**	**$61,538**	**$98,000**	$562,661	$1,054,684	$190,111
2048	27	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$965,119	$162,443
2049	28	**$122,770**	**$280,353**	**$108,918**	**$98,000**	$610,041	$1,200,917	$188,742
2050	29	**$122,770**	**$280,353**	**$57,866**	**$98,000**	$558,989	$1,129,999	$165,833
2051	30	**$122,770**	**$280,353**	**$1,333,891**	**$98,000**	$1,835,014	$3,756,889	$514,821
30 Year Total		**$3,683,102**	**$8,410,588**	**$12,307,589**	**$2,940,000**	**$27,341,279**	**$39,637,770**	**$16,225,904**

PC: Present Cost
FC: Future Cost
PV: Present Value

Appendix E4: ABRSD LCCA Summary Table - Electrified Option

ABRSD LCCA - Electrified Option								
Year	**Year Count**	**Electric Utility Cost PC ($)**	**Gas Utility Cost PC ($)**	**Investment Cost PC ($)**	**Maintenance Cost PC ($)**	**Total PC ($)**	**Total FC ($)**	**Total PV ($)**
2022	1	**$122,770**	**$280,353**	**$1,363,877**	**$98,000**	$1,865,000	$1,865,000	$1,865,000
2023	2	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$513,914	$479,872
2024	3	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$527,032	$459,523
2025	4	**$122,770**	**$280,353**	**$1,812,062**	**$98,000**	$2,313,185	$2,490,858	$2,027,941
2026	5	**$122,770**	**$280,353**	**$1,333,891**	**$98,000**	$1,835,014	$2,025,622	$1,539,927
2027	6	**$122,770**	**$280,353**	**$597,676**	**$98,000**	$1,098,798	$1,244,055	$883,114
2028	7	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$582,938	$386,398
2029	8	**$122,770**	**$280,353**	**$24,409**	**$98,000**	$525,532	$626,798	$387,950
2030	9	**$122,770**	**$280,353**	**$849,747**	**$98,000**	$1,350,870	$1,646,973	$951,853
2031	10	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$628,729	$339,299
2032	11	**$122,770**	**$280,353**	**$0**	**$98,000**	$501,123	$644,778	$324,911
2033	12	**$122,770**	**$280,353**	**$18,210,000**	**$92,600**	$18,705,723	$24,501,563	$11,528,786
2034	13	**$299,922**	**$157,228**	**$0**	**$92,600**	$549,750	$741,582	$325,825
2035	14	**$299,922**	**$157,228**	**$0**	**$92,600**	$549,750	$760,314	$311,927
2036	15	**$299,922**	**$157,228**	**$0**	**$92,600**	$549,750	$779,518	$298,622
2037	16	**$299,922**	**$157,228**	**$0**	**$92,600**	$549,750	$799,208	$285,885
2038	17	**$299,922**	**$157,228**	**$0**	**$92,600**	$549,750	$819,396	$273,691
2039	18	**$299,922**	**$157,228**	**$0**	**$92,600**	$549,750	$840,093	$262,017
2040	19	**$299,922**	**$157,228**	**$0**	**$92,600**	$549,750	$861,314	$250,841
2041	20	**$299,922**	**$157,228**	**$0**	**$92,600**	$549,750	$883,070	$240,142
2042	21	**$299,922**	**$157,228**	**$0**	**$92,600**	$549,750	$905,377	$229,899
2043	22	**$299,922**	**$157,228**	**$0**	**$92,600**	$549,750	$928,247	$220,094
2044	23	**$431,802**	**$75,849**	**$6,733,000**	**$86,000**	$7,326,651	$12,571,319	$2,783,302
2045	24	**$431,802**	**$75,849**	**$0**	**$86,000**	$593,651	$1,049,992	$217,071
2046	25	**$431,802**	**$75,849**	**$0**	**$86,000**	$593,651	$1,076,352	$207,780
2047	26	**$431,802**	**$75,849**	**$0**	**$86,000**	$593,651	$1,103,374	$198,888
2048	27	**$431,802**	**$75,849**	**$0**	**$86,000**	$593,651	$1,131,074	$190,376
2049	28	**$548,546**	**$0**	**$10,200,000**	**$103,300**	$10,851,846	$21,043,137	$3,307,251
2050	29	**$548,546**	**$0**	**$0**	**$103,300**	$651,846	$1,300,404	$190,841
2051	30	**$548,546**	**$0**	**$0**	**$103,300**	$651,846	$1,332,878	$182,649
30 Year Total		***$8,277,108***	***$5,315,765***	***$41,124,662***	***$2,836,500***	***$57,554,035***	***$86,224,909***	***$31,151,677***

PC: Present Cost
FC: Future Cost
PV: Present Value

Appendix F: Alternative Energy Credit Calculation Summary

Step 1: Use Formula from MA Guideline on Metering and Calculating Useful Thermal Output of Eligible Renewable Thermal Generation Units to determine Enet,out
https://www.mass.gov/doc/guideline-on-multipliers-for-renewable-thermal-generation-units-121517-final/download

8) Formula for Intermediate Split or VRF ASHPs

$$E_{net,\ out} = (COP_{OAT} * G) - G/0.44)$$

and

$$AECs = E_{net,\ out} * M$$

Where:
$E_{net,\ out}$ = Net thermal energy output equivalent

COP_{OAT} = The book value of the coefficient of performance at the outside air temperature as measured at the RTGU

G = Grid supplied electrical energy

Conversion of site to source nonrenewable fuel per MWh grid electricity = G / (0.44)

M = The appropriate multiplier as defined in the *Department's Guideline on Multipliers for Renewable Thermal Generation Units*

Note: All terms are the cumulative as-metered values. Unless otherwise indicated, all units in MWh

G (in MWh) comes from Salas O'brien thermal profile spreadsheets
COP comes from manufacturer provided literature for each ASHP

Building	ASHP Tonnage	COP	G (MWh)	Enetout (MWh)
AML	75	2.40	199	25
PSF	90	2.40	156	20
ATH	47	2.39	91	11
ABRHS	420	2.30	1180	32
RJ Grey	175	2.28	806	6
Parker Damon	106	2.30	485	13
Admin	100	2.35	306	24

Step 2: Determine multiplier based on system size
https://www.mass.gov/doc/guideline-on-multipliers-for-renewable-thermal-generation-units-121517-final/download

Small < 11T (0.134 MMBT	2
11T < Intermediate < 83T	1
Large > 83T	1

Table 1: APS Renewable Thermal Generation Unit Classification

Classification	Small	Intermediate		Large
AEC calculation basis	Calculated net renewable thermal output	Calculated net renewable thermal based on indirect metering	Calculated net renewable thermal output based on direct metering of fuel input	Metered net renewable thermal output
Solar thermal: evacuated tube and flat plate solar hot water	Collector surface area less than or equal to 660 sq ft	Collector surface area between 660 and 4000 sq ft	-	Collector surface area greater than or equal to 4000 sq ft
Solar thermal: solar hot air	-	Collector surface area less than or equal to 10,000 sq ft	-	Collector surface area greater than 10,000 sq ft
Solar sludge dryer	-	-	-	All
Eligible Biomass Fuel	-	-	Capacity less than or equal to 1 MMBtu per hour	Capacity greater than 1 MMBtu per hour
Compost heat exchange system	-	-	-	All
Air source heat pump: electric motor or engine driven	Output capacity less than or equal to 0.134 MMBtu per hour	-	Output capacity between 0.134 and 1.00 MMBtu per hour	Output capacity greater than or equal to 1.0 MMBtu per hour

3. Determination and Size of Multipliers

The Department of Energy Resources (Department) analyzed the costs of the different eligible renewable thermal technologies, and set the base multipliers such that value of the AECs generated by each technology type is similar relative to the costs of implementing the technology and various other factors.

The base multipliers for each technology and size classification are listed in the following table:

Technology	APS Renewable Thermal Generation Unit multiplier		
System size	**Small**	**Intermediate**	**Large**
Active solar hot water systems used for domestic hot water	3	3	3
Active solar hot water systems used for domestic hot water, space condition, or process loads	1	1	1
Active solar hot air systems	-	5	5
Solar sludge dryer	-	-	1
Ground source heat pumps	5	5	5
Deep geothermal	-	-	1
Air source heat pumps (electric or engine driven) – supplying less than 100% of building heating load[2]	2	-	-
Air source heat pump (electric or engine driven) – all other[2]	3	3	3
Compost heat exchange system	-	-	1
Biomass, biofuels, biogas	N/A	N/A	N/A

[1]Definitions of size classifications can be found in 225 CMR 16.05(4)(a) and Section 2 of the Department's *Guideline on Metering and Calculating the Useful Thermal Output of Eligible Renewable Thermal Generation Units*.
[2]Requirements for buildings using a small ASHP are described in the Department's *Guideline on Metering and Calculating the Useful Thermal Output of Eligible Renewable Thermal Generation Units – Part 1*

Step 3: Calculate AECs using Enetout and Multiplier (M)

$$\textbf{AECs} = \textbf{E}_{\textbf{net, out}} * \textbf{M}$$

Building	Multiplier	Enetout	AECs
AML	1	25	25
PSF	3	20	60
ATH	3	11	32
ABRHS	1	32	32
RJ Grey	1	6	6
Parker Damon	1	13	13
Admin	3	24	72

16.05: Eligibility Criteria for APS Alternative Generation Units

(1) Eligibility Criteria. A Generation Unit may qualify as an APS Alternative Generation Unit subject to the limitations in 225 CMR 16.05.

(a) Technologies. The Generation Unit shall use one or more of the technologies listed in 225 CMR 16.05(1)(a)1. through 6.

1. Gasification. This technology is no longer eligible because it was eliminated pursuant to M.G.L. c. 25A, § 11F½.

2. Combined Heat and Power. A Generation Unit that is operated to produce Combined Heat and Power may qualify as an APS Alternative Generation Unit, subject to the limitations in 225 CMR 16.05(1)(a)2.

a. CHP Metering and Reporting Requirements. A CHP Unit shall provide for the metering of electrical energy generated, Useful Thermal Energy produced, and fuel consumed; for calculating the net quantity of MWh for which Alternative Energy Attributes are qualified, and for reporting to the NEPOOL GIS of that net qualified MWh quantity in a manner prescribed in 225 CMR 16.05(1)(c), for each quarter of the Compliance Year. Monitoring, reporting, and calculating of electrical energy and Useful Thermal Energy produced in that quarter shall be expressed in MWh, and the total of all fuel and any other energy consumed in that quarter is calculated using the energy content of the fuel based on higher heating value.

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6. APS Renewable Thermal Generation Unit. A Generation Unit that uses one or more of the technologies provided in 225 CMR 16.05(1)(a)6.a. and generates Useful Thermal Energy may qualify as an APS Alternative Generation Unit, subject to the limitations in 225 CMR 16.05(1)(a)6.a. and the provisions in 225 CMR 16.05(4).

a. Eligible APS Renewable Thermal Generation Unit technologies and standards:

i. Air-source Heat Pump. An air-source heat pump Generation Unit uses compression and evaporation to transfer thermal energy from the ambient outdoor environment to a thermal load as Useful Thermal Energy. The Generation Unit must be designed to operate effectively in cold climates, such that the air-source heat pump provides meaningful net annual reductions in conventional energy use. Air-source heat pumps are provided APS Alternative Energy Attributes only when operating in a heating mode; that is, when transferring thermal energy from the ambient outdoor environment to a thermal load. An applicant must demonstrate to the satisfaction of the Department that the air-source heat pump is the primary source of heating for the residential Generation Unit, building, or process it serves, and meets the design criteria, as provided in the Department's *Guideline on Metering and Calculating the Useful Thermal Output of Eligible Renewable Thermal Generation Units*.

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